REC-OCE-70-55

REAERATION OF STREAMS AND RESERVOIRS ANALYSIS AND BIBLIOGRAPHY

D. L. King
Engineering and Research Center
Bureau of Reclamation

December 1970

BM-230 (6-70)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. REC-OCE-70-55	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Reaeration of Streams and Reservoirs, Analysis and Bibliography		5. REPORT DATE December 1970
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. L. King		8. PERFORMING ORGANIZATION REPORT NO. REC-OCE-70-55
9. PERFORMING ORGANIZATION NAME AND ADDRESS Division of General Research, Engineering and Research Center, Bureau of Reclamation, Denver, Colorado 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
		13. TYPE OF REPORT AND PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS Same		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Bureau of Reclamation responsibility for maintaining or enhancing the water quality associated with its projects has resulted in a comprehensive program of research in water quality and pollution control. A literature search and state-of-the-art review to determine the need for future research in reaeration of streams and reservoirs revealed a large number of references concerning the application of aeration methods and equipment to waste treatment. Generally, the application of this technology to aeration of large volumes of water such as rivers and reservoirs remains to be developed, although several applicable references were found. Questions regarding atmospheric reaeration in streams remain unresolved. Research is also needed regarding the aeration capability of hydraulic structures and control devices, development of new methods and equipment, effects of dissolved air on cavitation, and comparative economics of various methods and equipment. Ecological effects of reaeration are being considered in a separate review.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / *aeration/ *streams/ *reservoirs/ instrumentation/ oxygen sag/ mathematical analysis/ theory/ mass transfer/ equipment/ *dissolved oxygen/ methodology/ industrial waste treatment/ sewage treatment/ water quality/ efficiencies/ economics/ *bibliographies/ *reviews/ cavitation/ biochemical oxygen demand/ *reaeration/ oxygen requirements

b. IDENTIFIERS-- / cavitation control/ oxygen exchange/ empirical equations/ formulas

c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 131
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE $3.00

REC-OCE-70-55

REAERATION OF STREAMS AND RESERVOIRS ANALYSIS AND BIBLIOGRAPHY

by

D. L. King

December 1970

Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Ellis L. Armstrong
Commissioner

ACKNOWLEDGMENTS

This report was prepared in the Hydraulics Branch under the supervision of W. E. Wagner, Chief, Hydraulics Branch.

The assistance of the Technical Evaluation Section, Engineering Reference Branch, in preparing the bibliography was essential. G. W. DePuy provided supervision of this task. The work of Miss Linda Gray in locating and assembling the references is particularly appreciated.

The Applied Sciences Branch, under L. O. Timblin, cooperated in determining the scope of the study and in providing guidance during the preparation of the report. P. R. Tramutt and D. A. Hoffman were especially helpful in this respect. E. T. Lyons provided assistance in the collection of references.

The excellent work of Mrs. Leanne Morris in typing the manuscript of the bibliography several times is gratefully acknowledged.

The Science Information Exchange provided descriptions of current research activity.

The review and suggestions offered by Dr. Ernest C. Tsivoglou, Georgia Institute of Technology, were extremely helpful.

CONTENTS

CONTENTS—Continued

LIST OF TABLES

LIST OF FIGURES

NOTATION

Dimensions of mathematical terms are given in general terms of mass-length-time (M-L-T). For example, concentrations are expressed in the form of M/L^3. This form corresponds to English system units of lb/ft^3 or to Metric system units of mg/l . Similarly, the rate of mass transfer in general terms is expressed as M/L^2-T, corresponding to lb/ft^2–sec in English notation or g/m^2–sec in the Metric system.

PURPOSE

The literature survey was conducted for the purpose of preparing a summary of the state-of-the-art for defining research needs in the field of reaeration of streams and reservoirs.

CONCLUSIONS

The literature reflects a large amount of information on the waste treatment applications of reaeration. The use of diffusers and mechanical surface aerators is particularly well documented. Basic theories of mass transfer and bubble dynamics have also been widely investigated with emphasis on waste treatment.

Generally, the application of these theories and methods to large volumes of water such as rivers and reservoirs remains to be developed. Some work has been reported concerning the use of turbine injection, diffusers, and mechanical aerators for stream reaeration, and new devices such as the U-tube are being investigated; however, additional research is needed. The use of control devices, such as the Howell-Bunger valve, for reaeration, is in an early stage of investigation, and the reaeration capability of energy dissipators has had very little attention.

Reaeration of reservoirs has been primarily concerned with mixing by diffused air or pumping, with accompanying atmospheric reaeration at the water surface.

The effect of dissolved air on cavitation continues to be an area requiring further investigation.

Activity in mathematical simulation and prediction appears to be adequate. However, questions remain concerning atmospheric reaeration in streams, particularly correlation with hydraulic parameters.

There is an apparent deficiency in the area of economic analysis and cost comparison of methods and devices for reaeration. The methods of defining efficiency need to be standardized.

These conclusions point to the difficulties facing designers of equipment for reaeration of streams and reservoirs. The research activity in this field has not been collected into a set of criteria for design purposes.

APPLICATION

This report was prepared for the use of the Bureau of Reclamation in planning a program for research in reaeration. The bibliography provides references for use in the design and operation of reaeration equipment and for determining reaeration requirements.

INTRODUCTION

The Bureau of Reclamation has responsibility for maintaining or enhancing the quality of water associated with its projects.

Because of this responsibility, the Bureau is engaged in a comprehensive program of research in water quality and pollution control. This program includes determination of methods and techniques for water-quality monitoring and control, studies of water-quality parameters in large and small impoundments, investigation of eutrophication problems, preimpoundment studies for estimating future reservoir water quality, prediction of reservoir temperatures, laboratory studies for selective withdrawal, determination of basinwide influences on water quality, establishment and review of standards and criteria, studies of irrigation return flow, and studies of the relationships among structures, reservoir site preparation, and water quality.

Reaeration of streams and reservoirs offers promise in improving water quality. Examples of this application would be reaeration of low-level releases from stratified reservoirs for protection of the stream fishery or in-stream aeration of a polluted river to increase the capacity for assimilation of wastes. Techniques for reaeration of small streams and impoundments have been investigated and found to be applicable in varying degree. However, large streams and reservoirs introduce problems which do not allow immediate application of these techniques.

Reaeration has been used for many years in waste treatment, as in the activated sludge process. In-channel aeration for the recovery of badly polluted streams has received increasing attention.

Figure 1 shows the means by which oxygen enters or leaves a segment of a stream or reservoir. An easily defined contribution is through bulk flow; that is, the oxygen contained in the water entering and leaving the segment. Oxygen also enters the segment through precipitation which would also be considered as bulk flow. Other contributions are from chemicals, chemical reactions, and photosynthesis in plants. The most important natural addition of oxygen occurs through atmospheric aeration. Artificial oxygenation can be accomplished with air diffusers, mechanical aerators, or other devices.

In addition to bulk flow, oxygen leaves the system through decay of organic materials in the flow or on the bottom, plant respiration, and chemical reaction, such as nitrification (transformation of ammonia nitrogen to nitrates).

The earliest attempt to define the dissolved oxygen regime of a stream was made by Streeter and Phelps (S-37) with their oxygen sag equation:

$$\frac{dD}{dt} = K_1 L - K_2 D \qquad (1)$$

where

D	=	dissolved oxygen saturation deficit
t	=	time
L	=	biochemical oxygen demand (BOD)
K_1	=	decay (deoxygenation) rate constant
K_2	=	reoxygenation rate constant

The dissolved oxygen saturation deficit is defined as:

$$D = (C_s - C)$$

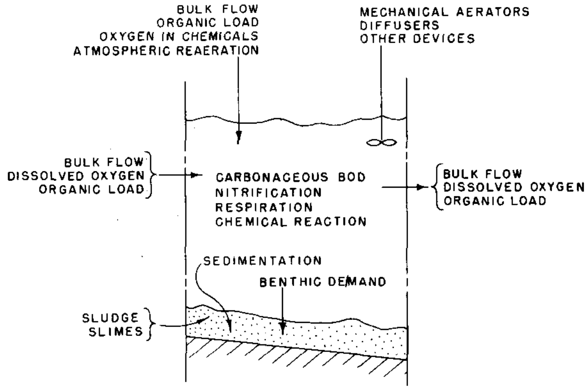

Figure 1. Oxygen balance in a finite element after Hann (H-3).

where

C_s	=	saturation concentration
C	=	initial existing concentration

The oxygen-sag equation may be misapplied because:

a. Deoxygenation and reoxygenation are not always first order reactions as shown in the equation.

b. The equation is idealized in that other means of oxygen inflow and outflow are not included.

c. Application to long stretches of the stream is not necessarily valid because of changing conditions and local variations.

An oxygen balance in a finite element, using the factors shown in Figure 1, more appropriately describes the actual physical situation. If the means of oxygen inflow or outflow can be described by differential equations, solution can be obtained by a method of finite differences. It is important to note, however, that Equation (1) is accurate under the conditions to which it is restricted.

DISSOLVED OXYGEN REQUIREMENTS

Dissolved oxygen is required for the survival and growth of many aquatic organisms, including fish. Also, the absence of dissolved oxygen leads to anaerobic decay of organic matter and results in undesirable esthetic qualities.

Federal recommendations for the levels of dissolved oxygen (C-22) for maintenance of fish and other aquatic life are quoted below:

"(1) For a diversified warm-water biota, including game fish, daily DO concentration should be above 5 mg/l, assuming that there are normal seasonal and daily variations above this concentration. Under extreme conditions, however, and with the same stipulation for seasonal and daily fluctuations, the DO may range between 5 mg/l and 4 mg/l for short periods of time, provided that the water quality is favorable in all other respects. In stratified eutrophic and dystrophic lakes, the DO requirements may not apply to the hypolimnion. In shallow unstratified lakes, they should apply to the entire circulating water mass.

"These requirements should apply to all waters except administratively established mixing zones. In lakes, such mixing zones must be restricted so as to limit the effect on the biota. In streams, there must be no blocks to migration and there must be adequate and safe passageways for migrating forms. These zones of passage must be extensive enough so that the majority of plankton and other drifting organisms are protected (see section on zones of passage).

"(2) For the cold water biota, it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and the general well-being of trout, salmon, and other species of the biota, DO concentrations should not be below 6 mg/l. Under extreme conditions they may range between 6 and 5 mg/l for short periods provided that the water quality is favorable and normal daily and seasonal fluctuations occur. In large streams that have some stratification or that serve principally as migratory routes, DO levels may be as low as 5 mg/l for periods up to 6 hours, but should never be below 4 mg/l at any time or place.

"(3) DO levels in the hypolimnion of oligotrophic small inland lakes and in large lakes should not be lowered below 6 mg/l at any time due to the addition of oxygen-demanding wastes or other materials."

OXIDATION

As discussed earlier, the dissolved oxygen regime of a stream is expressed by the Streeter-Phelps oxygen sag equation:

$$\frac{dD}{dt} = K_1 L - K_2 D \qquad (1)$$

In addition to bulk flow, the major depletion of oxygen occurs by decay of organic matter (BOD). Carbonaceous, or first-stage BOD is described by:

$$\frac{dL}{dt} = -K_1 L \qquad (1a)$$

The solution to this equation is given by:

$$L = L_a e^{-K_1 t} \qquad (1b)$$

where L_a = the initial BOD at the start of the decay process. This decay can occur in the flow or on the bottom. Oxygen demand also occurs by nitrification (C-26, S-32, S-33, W-9). The nitrification stage sometimes occurs after the carbanaceous stage is completed and can be very significant, particularly in reservoirs. Streeter (S-34, S-35) discussed this two-stage oxidation in detail. It must be emphasized that the oxidation process is complex and variable from one case to another. Determination of oxygen demand in streams and reservoirs should be attempted only with a complete understanding of the processes involved.

Other chemical reactions result in lesser oxygen depletion.

Krenkel, et al (K-26) discuss the effect of reservoirs on the removal of BOD by biological oxidation. Reduced velocity causes oxygen demand to take place closer to the point of waste discharge. Reservoirs can be advantageous by providing large volumes of water for dilution of wastes. If the reservoir is stratified, however, wastes can be confined to the hypolimnion and result in depletion of DO in that zone. DO depletion in the hypolimnion can also be caused by decay of sludge or other organic materials which have settled to the bottom of the reservoir. Settling of dead algae from the surface is a common example of this. If stratification persists for long periods of time, no atmospheric reaeration occurs, and DO can drop to zero in the hypolimnion. Therefore, low-level releases from a reservoir might have a desirable temperature, but be completely unacceptable in terms of DO.

Low DO also causes iron and manganese to return from the solid precipitated form back into solution. This condition can cause taste and odor problems in municipal water supplies.

Krenkel, et al discuss the variation of the decay rate constant with bacteria concentration, waste concentration, turbulent mixing, and temperature.

Variation of the decay rate constant K_1 with temperature is usually determined by the relationship:

$$K_1(T) = K_1(20)\,\theta^{(T-20)} \tag{2}$$

where

$K_1(T)$ = rate constant at T^o C
$K_1(20)$ = rate constant at 20^o C
θ = a constant, usually 1.047

Reference (K-26) includes a discussion of variation of θ.

Velz (V-7) states that BOD effects of bottom deposits may become acute where reservoir inflow velocities are less than 0.6 fps. Sludge deposits were found to return to suspension for velocities above 1.0 to 1.5 fps. The nature of the bottom material and currents within a given reservoir will, or course, determine the specific considerations for that reservoir.

Krenkel, et al (K-26) explain that reservoirs usually show improvement in water quality as the bottom deposits are oxidized or leached into solution and discharged. This applies particularly to debris which exists at the initial filling of the reservoir. The paper includes a tabulation of the oxygen demand of various types of soils and litter.

REAERATION

Basic Theories of Reaeration

Fick's first law of diffusion is expressed in vector notation as:

$$\vec{n}_A = W_A(\vec{n}_A + \vec{n}_B) - \rho\, D_{AB}\, \nabla W_A \tag{3}$$

where

A = gas
B = liquid
$\vec{n}_A$ = mass flux of A, M/L^2T
$\vec{n}_B$ = mass flux of B, M/L^2T
W_A = ρ_A/ρ mass fraction of A, dimensionless
ρ_A = mass density of A, M/L^3
ρ_B = mass density of B, M/L^3
ρ = $\rho_A + \rho_B$ = mass density of solution, M/L^3
∇W_A = mass density gradient, L^{-1}
D_{AB} = mass diffusivity of gas into liquid, L^2/T

The first term on the right side of the equation represents transfer by bulk flow while the second term represents transfer by molecular diffusion. Therefore, mass transfer by molecular diffusion (assuming a still liquid) is represented by:

$$\vec{n}_A = -\rho D_{AB}\, \nabla W_A \tag{4}$$

Considering the x-direction only, and changing to scalar notation, an alternate form is:

$$\frac{\partial m}{\partial t} = -Dm\,\frac{\partial c}{\partial x} \tag{5}$$

where

$\frac{\partial m}{\partial t}$ = rate of mass transfer per unit area, M/L^2T
Dm = molecular diffusivity, L^2T
$\frac{\partial c}{\partial x}$ = concentration gradient, M/L^4

Equation (5) describes steady-state transfer. If the concentration varies with time as well as distance:

$$\frac{\partial c}{\partial t} = Dm \frac{\partial^2 c}{\partial x^2} \qquad (6)$$

which is a form of Fick's second law of diffusion. A solution to this equation was found by Stefan (S-28, S-29) in 1878 and later applied by Phelps. The solution is:

$$C_t = C_s - 0.811(C_s - C_o)(e^{-K_d} + \frac{1}{9}e^{-9K_d} + \frac{1}{25}e^{-25K_d} + ...) \qquad (7)$$

where

$K_d = \frac{2\,Dmt}{4\,h^2}$

h = depth of water
D_m = molecular diffusivity
C_t = concentration at time t
C_s = saturation concentration
C_o = initial concentration, t = 0

The molecular diffusivity of oxygen into water has been estimated (K-3) to be 2.1 cm^2/sec at 20^o C.

The dissolved oxygen saturation deficit, D, is determined in aeration problems by the difference between the initial existing concentration, C_o, and the concentration at saturation, C_s. The saturation concentration depends upon the solubility of air or oxygen in water, which in turn depends upon temperature, pressure, and salinity. For example, with zero salinity, Figure 2, the solubility C_s varies from about 14.6 mg/l at 0^o C to about 7.5 mg/l at 30^o C, at atmospheric pressure. Phelps suggests a reduction in solubility of 10 percent for each 10,000 mg/l salinity (as chlorides). The saturation value increases with pressure.

As shown in Equation (1), the rate at which oxygen is absorbed is expressed as being directly proportional to the saturation deficit:

$$\frac{dD}{dt} = -K_2 D \qquad (8)$$

This equation can be integrated to give a solution in the form:

$$\frac{D}{D_o} = e^{-K_2 t} \qquad (9)$$

where D_o is the initial deficit.

An alternative form is:

$$\frac{D}{D_o} = 10^{-k_2 t} \qquad (10)$$

where

$k_2 = K_2/2.30$

Some references fail to show this distinction in the use of K_2 and k_2.

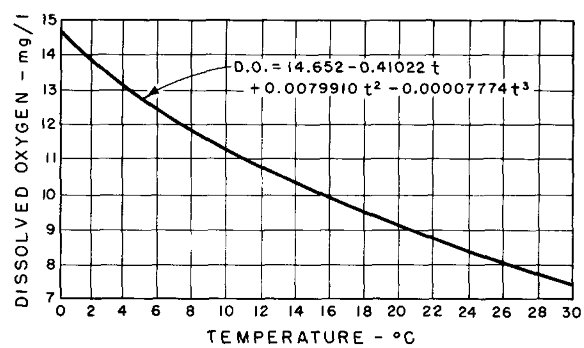

Figure 2. Experimentally determined and computed dissolved oxygen saturation values from Reference C-20

Evaluation of K_2 is the key to the development of an accurate description for the reaeration mechanism. Several theories have been proposed to provide an analytical basis for determination of K_2. Whitman (W-14), and Lewis and Whitman (L-11), in 1923 and 1924, presented the two-film theory. This theory makes four major statements:

1. Laminar layers of gas and liquid at the interface control the transfer process.

2. The laminar liquid film at the water surface controls the rate of oxygen transfer through the surface.

3. The film is saturated with oxygen at the surface.

4. The water is well mixed so that the concentration is uniform in the body below the laminar film.

Thus, a steep concentration gradient exists in the film and oxygen transfer takes place by molecular diffusion according to Fick's Law (Equation (5)), which becomes:

$$q = \frac{-A\,DmD}{b} \qquad (11)$$

where

q	=	rate of oxygen transfer, M/T
A	=	surface area, L^2
D_m	=	molecular diffusion coefficient, L^2/T
D	=	saturation deficit, M/L^3
b	=	stagnant film thickness, L

A liquid film coefficient, K_L, is introduced as a correlary to a rate constant, giving:

$$q = -AK_LD \qquad (12)$$

where

$$K_L = \frac{Dm}{b}$$

The film theory has not been generally accepted because the assumption of a laminar film is not physically realistic. It must also be noted that the film thickness b has never been measured; therefore, analytical evaluation of K_L is not possible.

The term K_La also appears in the literature. Dividing both sides of Equation (12) by the volume V expresses the rate of change in concentration:

$$\frac{q}{V} = -\frac{A}{V}K_LD \text{ or } \frac{dc}{dt} = -K_LaD \qquad (13)$$

where

$$K_La = K_L\frac{A}{V}$$

Objections to the film theory resulted in several alternatives being offered. Higbie (H-10) proposed his film penetration theory, which assumes that the transfer process takes place through alternate cycles of gas absorption and mixing. The water body is assumed to be stagnant for a short period during which oxygen is absorbed and downward molecular diffusion occurs. Then, the water is completely mixed and the cycle begins again. This theory led to an alternate expression for K_L:

$$K_L = 2\sqrt{\frac{Dm}{\pi t'}} \qquad (14)$$

where t' is the time required to complete one cycle of absorption and mixing. The penetration theory was the first to recognize the importance of turbulent mixing in renewing the unsaturated water exposed to the free surface. From a physical view, however, the assumption of alternate periods of stagnation and mixing is obviously unrealistic. Also, the penetration theory still contains the objectionable assumption of a surface film.

Danckwerts (D-2) extended the penetration theory by stressing the idea of surface renewal. He questioned the film concept and suggested a statistical distribution for mixing of individual elements. This approach seems more realistic, in view of the physical structure of turbulence.

The statistical distribution is expressed as:

$$f(t) = re^{-rt} \qquad (15)$$

where r is a rate of surface renewal, expressed as a fraction. Therefore, r is analagous to the reciprocal of t' in Equation (14). Danckwerts proposal thus results in:

$$K_L = \sqrt{Dmr} \qquad (16)$$

Dobbins (D-11) combined the film theory with the surface renewal theory by assuming continuous mixing below the film along with continuous renewal of the surface film and molecular diffusion within the film. Using Danckwerts' statistical distribution and a film thickness b, Dobbins derived:

$$K_L = \sqrt{Dmr}\coth\sqrt{\frac{rb^2}{Dm}} \qquad (17)$$

Note that as r approaches zero, K_L approaches that defined by the surface renewal theory: i.e.

$$K_L \rightarrow \sqrt{\frac{Dm^2}{rb^2}} \rightarrow \frac{Dm}{b}$$

Also, as r approaches a large number, K_L approaches that defined by the surface renewal theory; i.e.,

$$K_L \rightarrow \sqrt{Dmr.}$$

O'Connor and Dobbins (O-2) determined that Equation (17) would be identical to Equation (16) for values of r, b, and Dm which typify natural streams. They further postulated that streams had either nonisotropic turbulence or isotropic turbulence, depending on whether Chezy's C was less than or greater than 17, respectively. Many investigators have recognized that this appears to be a rather arbitrary way of defining isotropic turbulence. Actually, O'Connor and Dobbins, by their definition, found that most streams which they analyzed had isotropic turbulence. To test their concept of surface renewal, they performed laboratory experiments using an oscillating grid to produce turbulence. The results indicated a good correlation between the grid oscillation frequency and the observed k_2.

This theoretical and experimental work led to the expression:

$$k_2 = \frac{(Dm\,\bar{u})^{1/2}}{2.31\ H^{3/2}} \qquad (18)$$

for isotropic turbulence and

$$k_2 = \frac{480\ Dm^{1/2} S_e{}^{1/4}}{H^{5/4}} \qquad (19)$$

for nonisotropic turbulence.

In these equations:

$\bar{u}$ = average flow velocity
H = average flow depth
S_e = energy gradient

As mentioned above, most streams were found to conform to Equation (18). The measurements were made on reaches selected to minimize effects of bottom sludge deposits and algae. As much as 50 percent variation between theoretical values of k_2 and those determined by the field measurements was noted.

Empirical Studies

The foundation for empirical evaluation of k_2 was the work of Streeter and Phelps (S-37) on the Ohio River. Their oxygen sag equation was referred to earlier as Equation (1). By applying this equation, they indirectly measured values of k_2. Streeter and Phelps correctly hypothesized that the k_2 values should be related to temperature, depth, and turbulence in the stream. Assuming the temperature to be constant, they reasoned, with the aid of the solution to Fick's second law (Equation (7)), that k_2 should be approximately proportional to the inverse square of the depth. Also, they felt that the remaining factor, turbulence, should be directly proportional to a power function of the flow velocity. They thus derived the empirical relationship:

$$k_2 = \frac{Cv^n}{H^2} \qquad (20)$$

where C and n are constants that must be determined. The Ohio River measurements of Streeter and Phelps resulted in n values ranging from 0.57 to 5.40 and corresponding C values from 0.23 to 131. The need for caution in general application of Equation (20) is obvious.

Churchill, et al (C-12) used a strictly empirical approach to develop the relationship:

$$k_2(20) = 5.026\ \bar{u}^{0.969}\ H^{-1.673} \qquad (21)$$

where

$k_2(20)$ = reaeration coefficient at 20° C
$\bar{u}$ = average velocity, fps
H = mean depth of flow, ft

Multiple regression analysis was used with 509 sets of data to develop Equation (21), which is applicable to unpolluted streams.

This data collection program was accomplished with great care. The studies were conducted in streams below impoundments for which releases were low in dissolved oxygen and BOD. The reaches were chosen to have relative uniform hydraulic parameters of slope, depth, and shape. Generally, Churchill, et al attempted to eliminate those factors which tend to mask the true value of k_2. These data are generally accepted to be the most reliable available at the present time.

Owens, et al (O-9) combined the data of Churchill, et al (C-12) and Gameson, et al (G-2), and by regression analysis developed the equation:

$$k_2(20) = 9.41\ \bar{u}^{0.67}\ H^{-1.85} \qquad (22)$$

for velocities of 0.1 to 5.0 fps and depths of 0.4 to 11 ft. Using their own data for fast-flowing, shallow streams, they obtained the equation:

$$k_2(20) = 10.1\,\bar{u}^{0.73}\,H^{-1.75} \tag{23}$$

which gives a k_2 considerable higher than determined by data of Churchill, et al, Equation (21).

The experimental procedure and interference by bottom oxygen demand and plant photosynthesis make the results rather speculative, even though correction factors were applied. The restriction to fast-flowing, shallow streams is also an important limitation, even if the relationship could be accepted as valid.

Isaacs and Gaudy (I-11) used a rectangular laboratory flume to develop the expression:

$$k_2 = 3.053\,\bar{u}\,H^{-1.5} \tag{24}$$

The similarity of these empirical relationships with that originally proposed by Streeter and Phelps should be noted.

Much time and effort has been devoted to attempts to relate the reaeration coefficient k_2 to the hydraulic parameters of velocity and depth. Little progress has been made, for the following reasons:

1. Average values of velocity and depth are poor measures of flow conditions in a stream. Churchill, et al, for example, cautioned against applying their results to reaches with white water.

2. Even if these average parameters were acceptable correlations, they would be extremely difficult to measure accurately in the field.

3. Other effects, such as BOD, cannot be isolated when analyzing relatively long reaches.

Intuitively, the reaeration rate should be related to some measure of turbulence, as indicated in several of the investigations described above. Since turbulence is difficult to measure directly in the field, some investigators have attempted to relate k_2 to some indirect indicator of turbulence, such as eddy size or the rate of energy dissipation.

Krenkel and Orlob (K-23) applied kinetic gas theory to explain the transfer process. The change of reaction rate with temperature is given by:

$$k = A'e^{-\frac{Ea}{RT}} \tag{25}$$

where

k = the reaction rate
Ea = energy required by a molecule to be included in a reaction
R = the universal gas constant
T = absolute temperature
A = collision factor (analogous to a frequency)

Krenkel and Orlob reasoned that the movement of molecules from one equilibrium position to another in turbulent shear flow is analogous to the movement of molecules over a barrier of potential energy, for which a certain activation energy is required. Furthermore, they argued that some internal flow mechanism such as turbulence was required to sustain the absorption process. The longitudinal mixing coefficient was chosen as being the most appropriate. This coefficient was evaluated in the laboratory experiments by measuring the dispersion of an injected tracer. Correlation of this parameter with oxygen absorption measured in the laboratory flume gave:

$$k = 1.418e^{-\frac{Ea}{RT}}\frac{D_L}{h^2} - 0.0069 \tag{26}$$

where

D_L = longitudinal mixing coefficient
h = depth of flow

D_L/h^2 is proportional to the frequency at which gas molecules collide with the surface layers, and can be considered as a surface renewal rate.

Harleman and Holley (H-4) questioned the use of the longitudinal mixing coefficient as a measure of turbulence, explaining that the mechanism is one of dispersion caused by convective effects and is not, therefore, representative of turbulence. They suggested that the correlation was actually between k_2 and the average vertical eddy diffusivity.

Krenkel and Orlob also found a direct relationship between k_2 and the rate of energy dissipation in their laboratory flume. This relationship is:

$$k_2' = (1.141 \times 10^{-4})\, E^{0.408}\, h^{-0.660} \quad (27)$$

where

k_2' = k_2 corrected to 20° C
E = rate of energy dissipation per unit mass
h = flow depth

In open channel flow:

$$E = \bar{u}\, Se\, g \quad (28)$$

where

$\bar{u}$ = mean flow velocity
Se = energy gradient
g = gravity

The correlation between k_2 and E appears to be a very valuable result of the work, even though it was not given primary emphasis in the paper. However, in defining E, the difficulty remains in measurement of $\bar{u}$.

Krenkel and Orlob also suggest that the absorption rate of some gas should be in known proportion to that of another gas. In cases where the absorption rate of oxygen might be affected by BOD, for example, some other gas could be used to indirectly measure the oxygen absorption rate. The possible use of radioactive gases was mentioned.

Tsivoglou (T-28) describes such a method for direct measurement of the reaeration capacity of a stream. The method uses radioactive gas tracers to determine both dispersion and gas transfer. This represents the first known attempt to measure k_2 directly. All previous work has involved an indirect evaluation of k_2 through computation based on an oxygen-sag curve, even though the value thus obtained has been referred to as being "observed." The tracer method was developed in the laboratory and demonstrated in full-scale field studies.

Tsivoglou stresses that the tracer method should be considered as a primary standard, to which all the empirical results described earlier should be compared.

The O'Connor-Dobbins equation and the equation of Churchill, et al, were found to give approximate predictions for the Jackson River in Virginia. Tsivoglou states that comparisons of this type must be made with caution, because of errors in determining hydraulic parameters of the stream. More cross sections are necessary for accurate computations than are usually practical from a cost standpoint.

Effect of temperature.—The most commonly used description of the effect of temperature on k_2 was given by Streeter and Phelps (S-37):

$$k_2(T) = k_2(20)\, 1.047^{(T-20)} \quad (29)$$

where

$k_2(T)$ = reaeration coefficient at T° C
$k_2(20)$ = reaeration coefficient at 20° C

Krenkel, et al (K-26) summarize the work of other investigators. They state that O'Connor and Dobbins (O-2) and Krenkel and Orlob (K-23) predict a coefficient of 1.016. However, this value is incorrect and has apparently been confused with the correction coefficient for surface transfer as reported by Streeter, Wright, and Kehr (S-35).

Dobbins (D-11) maintains that the coefficient should be variable. Tsivoglou (T-28) found the relationship:

$$\frac{k_2(T_2)}{k_2(T_1)} = \theta^{(T_2 - T_1)} \quad (30)$$

where θ was 1.022 ± 0.003. Churchill, et al (C-12) found that θ = 1.024, based on a large number of measurements.

A relationship in the form of Equation (20) should generally apply to evaluation of k_2 for open structures and jets. However, where high velocities or severe surface turbulence occur, atmospheric reaeration is higher than that predicted by any of the empirical equations. Very little work has been done in this area. Tsivoglou's tracer method might be appropriate in this case.

This review of the state-of-the-art, with respect to natural reaeration of streams, indicates that attempts are being continued to better define correlation with hydraulic parameters. Empirically derived equations, most in the basic form of Streeter and Phelps' original work, continue to be used for lack of something better. Tsivoglou's tracer method for direct measurement of k_2 is a promising development, but remains restricted to in situ measurements. It is not yet suitable for prediction, because of the usual barriers in relating k_2 to hydraulic parameters.

It seems to the writer that correlation with some measure of energy dissipation is the only rational approach. Energy dissipated is the only means of summarizing activity within a finite segment of the stream. However, it is not difficult to imagine possible differences in stream segments with similar energy dissipation (such as a tranquil stream segment with a waterfall versus a segment with rapids).

Photosynthesis

Photosynthesis is the process by which carbohydrates are formed from water and carbon dioxide by chlorophyll in living plants. The reaction results in the release of oxygen.

Krenkel, et al (K-26) discuss the importance of photosynthesis as an oxygen source in reservoirs and summarize the thinking of several investigators. Experience has shown that the relative contribution of photosynthesis has ranged from unimportant to very important. Photosynthetic oxygen should be considered in the oxygen balance but should not be depended upon for waste assimilation. Knowledge in this subject has not advanced sufficiently to allow satisfactory application in practice. Hull (H-18, H-19, H-20) has published several papers on this subject. Other references include Edwards (E-5), Ignjatovic (I-2), Mackenthun (M-1), Verduin (V-8), and Winberg and Sivko (W-21).

Artificial Reaeration

Thackston and Speece (T-15) report that when mechanical devices are used for stream aeration, a level of 40 percent of saturation prior to reaeration is often considered as the upper limit for economical aeration. Aeration facilities should generally be located at the low point on the oxygen sag curve. Site choice is also influenced by the location of existing facilities (such as those with head loss), power availability, accessibility, and availability of personnel for operation and maintenance (T-15).

The break-even point of oxygen deficit versus cost of artificial reaeration depends on the characteristics of the particular device. The statement of 40-percent saturation may apply to many devices. However, a more appropriate general statement might be simply that efficiency of reaeration devices is directly proportional to the oxygen deficit, just as in natural reaeration.

Cascades.—Several British researchers (B-5) have investigated atmospheric reaeration at weirs. Data from four weir systems resulted in the empirical equation:

$$r = 1 + 0.11\, ab\, (1 + 0.046\, T)\, h \qquad (31)$$

where

- r = ratio of upstream saturation deficit to downstream saturation deficit
- a = coefficient for water quality (1.25 for slightly polluted water, 1.0 for moderate pollution, and 0.8 for sewage effluent)
- b = 1 for a free weir, 1.3 for the examined step weirs
- T = water temperature, $^{\circ}$C
- h = height of free fall, ft

The equation was partially verified for flows of 1 to 500 million gallons per day (mgd) (1.55 to 774 cfs). The equation also applies to loss of oxygen from supersaturated water. The authors state that most of the oxygen uptake resulted from splashing at the base of a free fall. Therefore, efficiency would be expected to increase with the number of steps, as indicated by the value of b. This is conjecture, although not entirely without basis. The phenomenon is likely a combination of insufflation, splashing, and turbulence (conjecture by the writer).

In an earlier reference, Gameson (G-6) presents a somewhat simpler relationship:

$$r = 1 + abh/2 \qquad (32)$$

where the parameters are as defined above, except that h is measured in meters. The effect of water temperature is not considered.

Very recently, Huckabay and Keller (H-16) have described a "cascade board." The development of this device was partially stimulated by Gameson's finding that the efficiency of aeration at weirs was directly related to the number of steps. The experimental apparatus consisted of a variable slope board covered with corrugated metal, with the corrugations transverse to the direction of flow. Tap water was used for the tests. Flow rate varied from 0.02 to 0.08 mgd/ft of width (about 0.03 to 0.12 cfs/ft).

The mass transfer coefficient K_La was expressed in terms of a "penetration factor," which in turn was related to a modified Reynolds number and the Schmidt number. The modified Reynolds number included flow rate, board length and inclination, and kinematic viscosity. The Schmidt number consisted of kinematic viscosity, density, and molecular diffusivity.

The authors conclude that the "cascade board" appears to be a promising aeration device. However, it is very difficult to extract information concerning actual mass transfer rates or coefficients from the paper. They state that additional investigations are being planned.

The writer suggests that these preliminary results should not be directly applied to aeration of large discharges, particularly in view of the very small discharges tested.

Aeration at weirs is also discussed by Albrecht (A-3, A-4), Grindrod (G-17), Manzack (M-5), Scott and Wisniewski (S-5), and Thackston and Speece (T-15).

Weirs as aeration devices have the advantages of being relatively maintenance free and requiring no direct energy expenditure. Where "free" head is available, weirs can be used very beneficially. However, if the head determines power loss or pumping requirements, cost of operation must be determined on that basis. Possible disadvantages of weir aeration systems are high capital cost, particularly for large structures, and low transfer efficiency.

Valves.—The Tennessee Valley Authority (TVA) (E-7) has evaluated the fixed-cone (Howell-Bunger) valve for aerating reservoir discharges. Tests were conducted with discharge either to a partially enclosed jet containment structure or to a tailwater pool. Aeration efficiency was found to be related to the discharge velocity. Jet thickness had little effect in the range covered by the tests. At discharge velocities less than 30 fps the discharge to the tailwater pool was more efficient than the confined discharge. For velocities above 30 fps either condition resulted in an oxygen increase greater than 80 percent of the initial deficit. The data show that the initial deficit had a noticeable, but ill-defined effect on the efficiency.

To the writer's knowledge, other control devices such as hollow-jet valves or slide gates have not been similarly evaluated for use in reaeration, even though they would probably have lower efficiency than the fixed-cone valve because of jet configurations which would result in less air-water contact. However, the reaeration effect might finally be determined by the design of the containment structure, when such a structure is used, or other appurtenances. The TVA work did not separate oxygen uptake by the jet from that in the catchment structure or tailwater pool. This would be useful information, if sampling methods could be devised.

The amount of DO increase in free chutes and tunnels and in energy dissipators such as stilling basins, baffled drops, and flip buckets also needs to be determined. Possible reaeration benefits of hydraulic devices and structures which are normally a part of the project plan should not be overlooked. In some cases departures from usual design practice may be required to increase the reaeration benefit.

Diffusers.—Using the penetration theory, gas absorption from rising bubbles can be expressed by (B-19):

$$\frac{dm}{dt} = \sqrt{\frac{4\,Dm}{\pi\,texp}}\,C_s \qquad (33)$$

where

$\frac{dm}{dt}$ = average rate of mass transfer, M/L^2T
Dm = molecular diffusivity, L^2/T
texp = exposure time of bubble (time required for liquid to pass one bubble diameter), T
C_s = solubility of the gas in the liquid, M/L^3

This theory assumes the liquid at the bubble surface to be at zero concentration of dissolved oxygen, and that no surface active agents are present.

This equation can also be expressed as:

$$\frac{dm}{dt} = \sqrt{\frac{4\,Dm\,v_t}{\pi\,D'}}\,C_s \qquad (34)$$

where

v_t = terminal velocity of the bubble, L/T
D′ = bubble diameter, L

Thus:

$$K_L = \sqrt{\frac{4\,Dm\,v_t}{\pi\,D'}} \qquad (35)$$

The bubble terminal velocity is given by:

$$v_t^2 = 4/3\,\frac{gD'}{f}\left(\frac{\gamma - \gamma_a}{\gamma}\right) \qquad (36)$$

where

g = gravity, L/T^2
f = friction factor (drag coefficient), dimensionless
γ = specific weight of water, M/L^3
γ_a = specific weight of air, M/L^3

However, $\left(\frac{\gamma - \gamma_a}{\gamma}\right) \approx 1.$

Therefore,

$$v_t^2 = 4/3 \frac{gD'}{f} \tag{37}$$

can be used.

The friction factor is dependent upon the Reynolds number:

$$R_e = \frac{v_t D'}{\nu}$$

where ν = kinematic viscosity, L^2/T.

A diagram of f versus Re for spheres is used for a trial-and-error solution.

For example, assume a 1/4-inch bubble and f = 0.44 as a first trial.

From Equation (37):

$$v_t^2 = \frac{4/3(32.2)(1/48)}{0.44}$$

$$v_t = 1.43 \text{ fps}$$

From Equation (38):

$$Re = \frac{1.43(1/48)}{(1.664 \times 10^{-5})} = 1{,}700$$

From the f-Re diagram, $f \approx 0.44$.

Therefore, the first trial is correct and v_t = 1.43 fps.

From boundary layer theory, the transfer efficiency of a bubble diffuser can be expressed in terms of the overall transfer coefficient or liquid film coefficient:

$$K_L = \frac{Dm}{D'} [2 + 0.664\,(Re)^{1/2}\,(Sc)^{1/3}] \tag{39}$$

(after B-19)

where

Dm = molecular diffusivity, L^2/T
D' = bubble diameter, L
Re = Reynolds number
Sc = ν/Dm, Schmidt number

This relationship is more complex than Equation (35), which does not account for viscous effects.

Johnson, et al (J-8) measured absorption rates of carbon dioxide, ethylene, and butene from single rising bubbles in a water column to determine the relationship:

$$Sh = 1.13\, Pe^{1/2} \left(\frac{d_e}{0.45 + 0.2\, d_e}\right)^{1/2} \tag{40}$$

where

Sh = Sherwood number, $\frac{K_L\, d_e}{Dm}$

d_e = equivalent bubble diameter, L
Dm = molecular diffusivity, L^2/T

Pe = Peclet number, $\frac{v\, d_e}{Dm}$

v = stream velocity or bubble velocity, L/T

which conformed quite closely to a theoretically derived equation.

An alternate form is:

$$K_L = 1.13 \left(\frac{Dm\, v}{0.45 + 0.2\, d_e}\right)^{1/2} \tag{41}$$

These equations apply for Reynold's numbers between 500 and 20,000. The bubbles were oblate spheroids, ellipsoids, or spherical caps, depending on the equivalent diameter, which ranged from 0.4 to 2.0 cm. Equation (41) applies to equivalent diameters of 0.6 to 4.0 cm. This result can be compared with the theoretical K_L for spherical bubbles from Equation (35):

$$K_L = \left(\frac{4\ Dm\ v}{\pi\ d_e}\right)^{1/2} \qquad (42)$$

with appropriate changes in notation, and with Equation (39). The writer suggests that Equation (41) be used. The limitation to spherical bubbles in the other cases is not practical.

The ratio of oxygen transferred from a bubble to the volume of oxygen contained in the bubble determines the transfer efficiency.

Similarly, the efficiency of a diffuser system is determined by the ratio of oxygen transferred to oxygen supplied:

$$E = \frac{TR}{SR} \times 100 \qquad (43)$$

where

E = efficiency, percent
TR = oxygen transfer rate, M/T
SR = oxygen supply rate, M/T

Eckenfelder (E-1) summarizes the work of several other investigators and presents the relationship:

$$K_L = C \frac{Dm}{D'} \frac{Re\ Sc^{1/2}}{H^{1/3}} \qquad (44)$$

where C is an empirical constant,

H is the tank depth.

This equation is similar to those presented previously, with the exception of the inclusion of tank depth. It also must be noted that Equation (44) holds only for the narrow range of Reynolds numbers of 50 to 500.

Eckenfelder also formulates an overall mass transfer coefficient for evaluating performance of a commercial diffuser:

$$K_L a = \frac{c\ G_s^{(1-n)}\ H^{2/3}}{V} \qquad (45)$$

where

K_L = liquid film coefficient, min^{-1}
a = ratio of total bubble surface area to liquid volume, A/V, ft^{-1}
c = a constant
G_s = airflow, SCFM (at standard temperature and pressure)
V = tank volume, ft^3
(1-n) = variable exponent which is a function of bubble size
H = tank depth, ft

The exponent of H has actually been found to vary from 0.45 to 0.77 depending on the type of diffuser and the particular application. The exponent (1-n) might vary from 0.8 to 1.4, with higher values for smaller bubbles and correspondingly greater transfer rates.

Eckenfelder also summarizes the velocity and shape characteristics of air bubbles in water as they vary with the Reynolds number of the bubble. At $Re < 300$, the bubbles are rigid spheres which rise either in a rectilinear or a helical motion. For Re = 300 – 4,000, the bubbles are ellipsoidal in shape and rise with a rectilinear, rocking motion. The bubbles are shaped as spherical caps for $Re > 4{,}000$.

Tyler (T-34) produced one of the early proposals for the use of diffusers for supplemental reaeration of streams. He reported an average efficiency of about 7 percent, using carborundum plates and porous tubes under 12 feet of water.

Experience with diffusers in waste treatment is well documented. Reference (T-3) contains an excellent summary of diffuser types, design, and economics as applied to waste treatment.

Diffusers are classified (T-3) as porous or nonporous. Porous diffusers consist of plates or tubes, usually formed with a ceramic of silicon dioxide or aluminum oxide held in a porous mass with a ceramic binder. Porous diffusers may also consist of nonceramic plastic-wrapped tubes or plastic-cloth tubes.

Nonporous diffusers exist in several types. The nozzle and orifice types are made of metal or plastic with larger openings (and larger bubbles) than the porous diffusers. The valve type has a disk or valve which closes when the air supply is cut off. The valve type produces large bubbles. The shear type has a square shape and an open top through which water enters, thus "shearing" the bubbles into smaller sizes. The water jet type consists of a system of nozzles which entrain air supplied to one side of the nozzle. For temporary use or in unusual circumstances, perforated or slotted pipes are used. This type is usually used only in shallow water, has a low efficiency, and tends to clog and corrode readily.

Plain jets (Sparjers) are often referred to in the literature. Reference (T-3) describes the Sparjer as a controlled air-release device which utilizes a cluster of four high-velocity short-tube orifices to disperse the air in a controlled pattern. The bubbles break into smaller bubbles a short distance above the device. Orifice sizes vary from 1/8 to 5/16 inch, depending on the application.

Diffuser efficiencies as high as 17.5 percent have been measured in aeration tanks. However, this efficiency seems unusually high, in light of many other references which indicate efficiencies ranging from 2 to 8 percent. Oxygen transfer was found to increase with depth. This is due to the increase in the saturation concentration caused by an increase in pressure. The oxygen saturation deficit is larger, and oxygen transfer occurs at a faster rate.

Fischerstrom (F-5) suggests the use of diffusers close to the surface with introduction of relatively large quantities of air. Several examples of the application of this method in Sweden are described. The method is based on the idea that although transfer efficiency is reduced by introducing air at shallow depths, more air can be supplied for the same amount of power required for deeper diffusers.

The number of diffusers required for a given application depends upon the recommended flow rate per diffuser, which usually varies between 4 and 15 cfm/diffuser (0.1 to 0.4 cu m/min). Diffuser spacing should be 6 to 24 inches. Clogging of diffusers can be eliminated by adequate filtering of the air supply.

Installation of a diffused air system requires blowers and housing, air piping and headers, diffusers and supports. Annual operating expense consists of power cost and equipment maintenance. Clogging is the most serious maintenance problem (T-4). Reference (T-4) includes aids for economic analysis.

Palladino (P-1) used drilled pipe diffusers under 4 to 5 feet of water and attained an efficiency of only 1.7 percent.

Wisniewski (W-23) reports the use of a bed of diffuser plates on the Flambeau River in Wisconsin, with efficiencies of 6 to 8 percent.

As mentioned earlier, the efficiency depends on the initial level of DO below the saturation level.

Diffusers have been widely accepted as aeration devices and may have application to specific problems of reaeration of streams and reservoirs. However, the writer feels that because of the usual low efficiencies, high initial cost, and possible maintenance problems, alternate devices should be considered. It is the writer's opinion that diffusers probably have an advantage when used in reservoirs, both for direct aeration and mixing. However, their use in streams might be questionable.

Mechanical aerators.—Mechanical aerators accomplish reaeration at the water surface and also often meet mixing requirements in waste treatment practice. Reference (T-3) contains an excellent description of mechanical aerators, including photographs.

Mechanical aerators can transfer oxygen by surface renewal and interchange (surface aerators) or by dispersing compressed air fed below the surface to a rotating agitator or turbine (turbine aerators).

The updraft-type surface aerator lifts large volumes of liquid above the surface for exposure to the atmosphere. The plate-updraft type produces a high level of surface turbulence. The turbine-updraft type (or combination type) consists of a turbine with a pipe or sparge ring discharging air below the rotating blades.

In the downdraft type, air is supplied by the negative head produced by the rotor. External blowers or compressors are not required.

The brush-type surface aerator consists of a horizontal revolving shaft with combs, blades, etc., extending below the water surface.

The efficiency of a mechanical aerator is expressed as:

$$N = \frac{K_L\, a\, D\, W}{P} \tag{46}$$

where

N = efficiency, lb (or g)/hp-hr
$K_L a$ = overall transfer coefficient, T^{-1}

D = oxygen deficit, M/L^3,
W = capacity of system, L^3
P = brake horsepower, hp

The numerator of Equation (46) can be measured in the field as a single quantity, the weight of oxygen transferred per unit time.

Burns, et al (B-33) describe the use of a plate-updraft-type surface aerator placed at the location of minimum DO in a stream. With an initial DO deficit of 100 percent, an efficiency of 2.15 lb/hp-hr (1.61 lb/kwhr) was obtained. A discussion of the paper describes German use of floating aerators for which an efficiency of 1.75 lb/kwhr (2.34 lb/hp-hr) was obtained at 50 percent DO deficit.

Downing, et al (D-15) describe tests of two types of mechanical aerators of British manufacture (Searle aerator and Simplex cone). Effects of temperature, immersion depth, and surface-active agents were determined. Maximum efficiencies for the two types were about 1,450 g/kwhr, or approximately 3.2 lb/kwhr, based on total power consumption. The tests were conducted in full-scale laboratory apparatus with 100 percent DO deficit. The paper also discusses the Kessener brush aerator and the Sheffield system of rotating paddles; however, no efficiency data are given.

Thackston and Speece (T-15) discuss a floating aerator with two 10-foot-diameter rotating turbines in vertical draft tubes. Low-lift, high-capacity pumps throw the water into the air from the periphery of the turbines (updraft type). The aerators were used in a canal and efficiencies were 1.3 lb/hp-hr (1.0 lb/kwhr) for flows less than 3,000 cfs and 3.4 lb/hp-hr (2.5 lb/kwhr) for flows greater than 4,400 cfs. Initial DO level was not stated.

In the writer's opinion, mechanical aerators have definite application to stream reaeration, except where they might present hazards to recreation or navigation. In some locations, noise of operation might also be objectionable. Initial cost of the equipment is high. However, a wide variety of types is available. Application to reservoir reaeration is doubtful. The epilimnion is usually well mixed and relatively high in dissolved oxygen. The mixing effect of the mechanical aerators would not, in most cases, extend into the deeper layers of the reservoir.

Turbine injection.—Where power turbines are set above tailwater level, which is usually the case, the vacuum produced in the draft tube can be used to draw air from the atmosphere. Vents can be designed to open automatically, can be permanently open, or can be valved for closer control. Another method is to introduce compressed air either above or below the turbine runner. This approach is necessary whenever a natural draft due to vacuum does not exist. Many hydroplants include provisions for injection of air for the purposes of cavitation suppression or control of draft tube surging (D-21). Therefore, the mechanics of venting, etc., are well known. However, in most cases the increase in DO downstream has been an incidental and unmeasured benefit.

Wagner (W-1, W-2, W-3, W-4) describes early studies in turbine aeration and gives the first detailed discussion of operation, including cost and efficiency.

The most extensive and well documented experience in turbine aeration is in Wisconsin (S-5, S-6, W-16, W-17, W-19, W-23). However, this experience is limited to installations with heads of 8 to 21 feet.

Scott, et al (S-6) describe the results of turbine venting at Pixley Dam on the Flambeau River in Wisconsin. The turbines are the double-runner horizontal type. Air was injected in the annular space between the runner ring and the cone-shaped part of the draft chest which surrounds the runner ring. According to the authors, air injection resulted in a power loss because of reduction in discharge through the turbine. Reaeration efficiencies are stated in terms of this power loss. The maximum DO gain at Pixley Dam was 4.87 lb/kwhr. 37.3 percent of the supplied oxygen was absorbed.

Power loss is usually determined by reading power gages in the powerhouse. Scott and Wisniewski (S-5) discuss the determination of true power loss. They state that, although the power output is reduced, water is also saved for later generation because of reduced discharge, thus partially offsetting the cost of the immediate power loss. This statement should not be accepted without reservation. It seems incorrect to attempt to justify a reduction in efficiency in this way.

Wisniewski (W-23) reviews the status of stream aeration on three Wisconsin rivers as of 1965. The paper gives an evaluation of capital and operating costs for turbine aeration and suggests that a power loss of about 5 percent should be expected for low-head dams (15 to 25 feet), with less power loss expected for high dams (over 100 feet). As of 1961, 18 dams included turbine aeration. The range of efficiencies was 1.82 to 5.43 lb/kwhr in terms of power loss.

Palladino (P-1) evaluates turbine venting for reaeration of the Kalamazoo River in Michigan. The venting added 2 lb/kwhr, with initial DO less than 1 mg/l. Actual addition of oxygen was 0.5 mg/l. Noise in the vent indicated undersizing.

Lee (L-9), in a discussion of Wisniewski's paper, describes aeration experiments with Francis turbines at the Wylie Station plant on the Catawba River in South Carolina. He stresses the importance of turbine characteristics, load, wheel setting elevation with respect to tailwater elevation, vacuum breaker arrangement, and draft tube dimensions and shape with regard to the reaeration effectiveness. Bureau of Reclamation experience with draft tube air injection for control of cavitation and surging in high-head installations has shown an increased efficiency. The slight reduction in discharge is more than offset by the effects of smoother operation. Under these circumstances, draft tube aeration could be considered to be a cost-free benefit.

The possibility of using the draft tubes of dormant turbines for reaeration has been considered, with specific reference to equipment which is no longer used because of age. A logical extension to this idea would be the use of turbines for reaeration during offpeak periods. Reaeration benefits would have to be balanced against cost of water loss.

Since most Bureau of Reclamation projects include hydraulic turbines, the writer feels that this method of reaeration should be carefully considered. However, considerable research will be required. The literature, including the references discussed above, does not provide a clear understanding of the advantages and disadvantages of turbine injection, particularly for high-head installations. Also, experience in turbine venting has not been widely published in comparison with diffusers and mechanical aerators. This is probably because of the wide application of the latter methods to waste treatment.

Hydraulic guns.—The "Aero-hydraulic gun" is described by Bryan (B-27). The device consists primarily of a vertical pipe, 6 inches to 3-1/2 feet in diameter, into which large bubbles are introduced intermittently and automatically. The bubble completely fills the pipe and discharges water from the top of the pipe as new water is drawn through ports near the bottom of the pipe. The device was first used in ice-prevention and local wave control and in aerobic sewage treatment. Aeration occurs through generation of high-velocity surface currents, transfer from the bubbles, and generation of a surface boil. The design is optimized according to the nature of the requirement. Efficiency with an initial zero DO at 20° C is approximately 1.6 lb/brake hp at an aeration capacity of 1 lb/hr (1.2 lb/kwhr), depending upon the details of the design and the primary purpose of the installation. The primary effect of the device is in mixing the water body in which it is placed. It is a relatively low-efficiency aerator and thus has questionable value as an instream device.

U-tubes.—The development of the U-tube device in the Netherlands was reported by Bruijn and Tuinzaad (B-28) in 1958. Further work has been carried out recently by Speece and reported by Speece and others (S-21, S-23, S-24, S-25, S-26). As the name implies, the device is shaped like a U-tube, in which the water flows downward from the entering channel then upward into the exit channel. The two legs can be formed by placing a vertical baffle in a trench.

The main advantages of the U-tube device are:

1. A high rate of bubble surface renewal resulting from turbulence caused by the buoyant force of the bubble.

2. Longer bubble contact time in the downward leg because of downward flow counteracting the buoyancy of the bubbles.

3. Bubble pressurization with increased saturation concentration, resulting from hydrostatic head.

Air is introduced at the top of the downward leg by a natural drop such as a weir, by a constriction in the flow passage, or by injection from a diffuser. Where head loss can be tolerated, natural entrainment is, of course, preferable.

Speece, et al (S-25) describe small-scale experimental studies. Effects of air-water ratio, velocity, depth, injection depth, bubble size, and internal flow constrictions were evaluated. The pilot system was made of 4-inch-diameter pipe. The study showed that water with initial DO of zero could be completely saturated with one pass through a 40-foot-deep U-tube with air injection of 20 percent of the water volume. The paper states that the transfer economy and capital cost of the U-tube are competitive with conventional aeration systems, which are economical only when reaerating waters with low initial DO. The design of U-tube aeration systems has been discussed in a recent paper by Speece and Orosco (S-26). A design example is given, which includes a cost analysis. The U-tube is considered by the authors to be the best device available for saturating a flow with oxygen, but not necessarily advantageous over mechanical surface aerators when producing 40 to 50 percent saturation.

The writer feels that this device shows promise for application to Bureau of Reclamation problems. However, the U-tube has not yet been used for aeration of large open-channel flows. Therefore, application of the results of the small-scale studies reported in the literature may or may not be appropriate. Consideration should also be given to possible plugging of the device with coarse sediment, weeds, or ice.

Venturi tubes.—Bayley and Wyatt (B-8) describe an experimental study in which air was injected at the 3/4-inch-diameter throat of a Venturi section in a 1-1/2-inch-diameter pipe. Oxygen absorption was measured at various airflow rates, for several water discharge rates. DO was zero at the start of each test. Air was admitted naturally as the result of the vacuum at the throat.

The increase in DO varied directly with the ratio of air to water in the system. The presence of air in the Venturi caused an increase in head loss, as compared to the loss with no air present. The loss also increased with increased velocity. The study did not separate these effects.

The maximum transfer efficiency obtained was 850 g/kwhr of energy loss (1.9 lb/kwhr). The maximum efficiency occurred only when the DO absorbed was less than 0.5 ppm. For higher absorptions (and higher velocities) efficiency was reduced because of increased head loss. The paper states that some reduction in efficiency resulted from small bubbles coalescing into large bubbles in the main pipe, thus reducing the bubble surface area.

Additional experiments were performed in which the flow was discharged directly into a tank. The bubbles were thus allowed to rise from the exit of the pipe to the water surface. A maximum efficiency of 1,150 g/kwhr (2.5 lb/kwhr) was obtained with this method.

Addition of detergents resulted in a substantial increase in efficiency, which is in contrast to observations made on diffused air systems. The authors speculate that this is due to an increase in the interfacial area of the rising bubbles, but do not give any confirmation.

More recent experiments were performed by Jackson and Collins (J-2) on two different scales of a Venturi aerator.

The writer feels that this method would be useful only in reaeration of relatively small discharges and volumes, as in waste treatment.

Pressure injection.—Thackston and Speece (T-15) review a method in which a small amount of the total water volume is supersaturated with air, under pressure, then released into the main flow. Air comes out of solution and reaerates the rest of the flow. No efficiencies were given.

Miscellaneous methods.—Thackston and Speece (T-16) report the use of a siphon which supplies spray nozzles downstream from a dam. Actual amounts of the DO increase were not given. Bulicek (B-30) describes an unsuccessful attempt to save fish by aerating a stream with paddle wheel steamers.

Hypolimnion reaeration.—Situations occur in which it is desirable to reaerate the bottom waters of a lake or reservoir without destroying the stratification by mixing. For example, where downstream releases are used for drinking water or maintenance of certain fish life, it is beneficial to release cold water. One obvious way to fill these needs is to selectively withdraw cold water from the reservoir, then reaerate the stream. The devices described thus far generally apply to this approach. Bernhardt (B-15) proposed a method by which reaeration of the hypolimnion could be accomplished within the reservoir without destruction of the thermocline and eplilimnion. Efficiency was determined to be 2.1 lb/kwhr. The corresponding transfer efficiency was 50 percent, based on measurement of the oxygen content of the rising bubbles.

The system includes an open-ended vertical pipe which extends from near the bottom of the reservoir to above the water surface. Air is introduced through a diffuser at the bottom of the pipe. Four distribution pipes, branching from the vertical pipe, are located just below the thermocline. The rising air causes the water within the pipe to rise, then flow outward through the distribution pipe. The vertical pipe extends far enough above the surface so that water is unable to overflow at the top.

Bernhardt's paper also includes a short summary table of reoxygenation capacity for several reservoir aeration systems. A condensed version of this table is given below:

Table 1

EFFICIENCIES OF SEVERAL REAERATION DEVICES

Method	Efficiency (lb/kwhr)
Diffused air, mixing	*0.3-4.3
Mechanical turbine aerators	1.3-5.6
Mechanical pump, mixing	1.0
Aerohydraulic gun	1.4
Hypolimnion aeration and mixing	2.1

*Transport of water to surface allows atmospheric reaeration in addition to oxygen transfer from bubbles.

Reaeration by reservoir mixing.—Improvement of reservoir water quality by artificial destratification, using either compressed air or mechanical pumping, has been described by Symons, et al (S-42–S-49). Before using this approach, the necessity and desirability of destratification must first be determined. In many cases, stratification may be determined to be beneficial; for example, in controlling the temperature of downstream releases. Also, the work described has been limited to relatively small impoundments (less than about 5,000 acre-feet). Energy requirements for mixing large reservoirs might be prohibitive. However, mixing of selected zonces of reservoirs might prove to be economically feasible.

A recent paper by Symons, Carswell, and Robeck (S-49) describes test destratification of reservoirs up to 2,900-acre-feet volume using either mechanical or diffused air pumping. Results from one test showed reoxygenation efficiencies of 0.7 lb/kwhr for mechanical pumping and 1.7 lb/kwhr for diffused air pumping.

Reaeration with Molecular Oxygen

Molecular oxygen has a solubility in water approximately five times greater than oxygen in equilibrium with air. Therefore, correspondingly smaller amounts of molecular oxygen are required for reaeration. However, molecular (or tonnage) oxygen must be manufactured, and the advantage of less quantity might be offset by higher unit cost. Where dissolved nitrogen might have adverse effects on fish, use of molecular oxygen instead of air should be given special consideration.

Amberg, et al (A-7, A-8, A-9) discuss injection of molecular oxygen into a Pelton turbine. Separate runs were made using air or molecular oxygen. A single vent was placed directly above the runner blade, or a sparge ring above the runner blade was used.

The average results were as follows:

Single vent, air:	Initial DO = 8.9 ppm Added 0.529 lb oxygen/kwhr (0.71 lb/hp-hr) of power loss
Single vent, oxygen:	Initial DO = 7.2 ppm Added 13.9 lb/kwhr (18.6 lb/hp-hr)
Sparge ring, oxygen:	Initial DO = 7.8 ppm Result not clear

Turbine vibration was noted with the single vent, but not with the sparge ring.

Speece (S-22) discusses several sources of information which indicate absorption efficiencies ranging from 14 to 55 percent for various methods. He suggests that the cost of molecular oxygen depends upon the quantity used and whether the demand is seasonal or continual.

The cost for large quantities used throughout the year is estimated at $7-8/ton. For a 3-month-per-year operation, the cost might be $20-60/ton, with the cost proportional to the amount used. About 350 kwhr of power are required to produce 1 ton of oxygen. Speece states that for a year-around usage of 20 tons or more of oxygen per day, it would be economical to place an oxygen plant on the site of use. This reference reviews several theories of oxygen transfer and discusses several methods of introducing pure oxygen to water, including a downflow bubble contact system and injection into penstocks.

With injection into penstocks, the initial bubbles should be sized so that oxygen transfer can be essentially complete before reaching the turbine. Free bubbles can have an adverse effect on turbine operation.

Injection of molecular oxygen bubbles from a diffuser at the bottom of a reservoir has been suggested. The bubbles would be sized so that most of the oxygen transfer would be accomplished within the hypolimnion. Thus, the stratification would not be disturbed.

Use of liquid oxygen (LOX) is being investigated, but has not yet been reported.

Investigations of the use of molecular oxygen for reaeration are relatively recent. This technique should, in the writer's opinion, be investigated thoroughly for possible application to Bureau of Reclamation problems.

Overall Comparison of Artificial Reaeration Methods

Efficiencies of several reaeration devices were compared in Table 1. Table 2 summarizes efficiencies (in lb oxygen/kwhr), advantages and disadvantages of the various devices and methods which have been discussed. Obviously, it is difficult or impossible to make an evaluation on the basis of efficiencies alone. The efficiency is strongly dependent upon the initial DO deficit which is not always stated in the references. Also, Table 2 shows that the ranges of efficiencies are quite similar for the various methods.

Therefore, choices must be made on the basis of other factors such as the required application, the advantages and disadvantages of use, first cost, and maintenance cost. Relative costs are indicated under advantages and disadvantages for some of the methods listed in Table 2.

Thackston and Speece (T-15) present a limited comparison of annual costs of reaeration by diffusers, turbine injection, cascade aeration, and mechanical surface aerators. This comparison is given in Table 3.

The cost of turbine aeration assumes an efficiency of 3.5 lb/kwhr and a power value of 1 cent/kwhr. The capital costs for all methods are converted to annual costs by using a 5-percent interest rate and 20-year life. The sources of data are given in (T-15).

Imhoff (I-5) reports the comparative costs of three alternative methods applied to the Ruhr River in Germany:

Mechanical aeration	0.81 DM* for removal of organic pollution of one population equivalent
Turbine aeration	0.22 DM per population equivalent
Treatment plant expansion	4.0 DM per population equivalent

*German currency 4 DM ≈ $1.00 U.S.

Mechanical aeration was found to be 3.7 times more costly than turbine aeration (Table 3 shows a factor of 3.1). The marked advantage of instream aeration over treatment plant expansion in this case should be noted.

Krenkel, as part of unpublished seminar notes on reaeration, has provided a summary of costs of aeration systems determined by Bernhardt. This summary is reproduced in Table 4.

Table 4 shows that cascades (constructed only for the reaeration benefit) are not as competitive as suggested by Table 3, due to their relatively low oxygenation capacity. The cascade listed in Table 4 also had a relatively very low first cost. Both Tables 3 and 4 show that turbine aeration is very competitive. Bernhardt's hypolimnion aeration method is the next most competitive of the methods listed in Table 4, followed by floating aerators, U-tubes, turbo oxyders, cascades, and diffusers.

Whipple and Coughlin (W-11), in a recent paper, describe tests on the Passaic River, New Jersey, conducted for the purpose of comparing costs of mechanical aerators and diffusers. The efficiency of the mechanical aerator varied from approximately 2.0 to 3.0 lb/hp-hr (2.7 to 4.0 lb/kwhr), increasing with an increase in stream discharge. The transfer rates of the diffusers were about two-thirds those of the mechanical aerators under comparable conditions. Table 4 indicates similar results.

Complete cost analyses were made for multiple unit installations of either mechanical aerators or diffusers. The total annual costs showed that the mechanical aerators had a marked advantage.

The paper also includes a brief discussion of the possible environmental effects of aeration installations.

Other Applications of Reaeration Methods

Cavitation control.—In 1963 Robertson (R-9) suggested that the effect of gas or air content on cavitation was the least understood of any of the scaling factors in cavitation testing. There is little evidence that the situation has changed since that time. Robertson's discussion includes the "pseudo-cavitation" which can occur above vapor pressure due to the release of dissolved gases at low pressures.

It is generally accepted that true cavitation results from the growth and collapse of gas nuclei other than free bubbles. The necessary nuclei are believed to originate

Table 2

OVERALL COMPARISON OF REAERATION METHODS

Device	Efficiency	Advantages	Disadvantages
Diffusers (including reservoir mixing)	2-8 percent (Est. 1-3 lb/kwhr)	Many types available.	Clogging. Requires filtering of air. Relatively low transfer efficiency. High first cost.
Mechanical aerators	2-5 lb/kwhr	Many types available. Natural or forced-air admission. Valves, piping, blowers, etc., are not required.	Swimming hazard. Obstructs channel. High first cost.
Turbine injection	2-6 lb/kwhr (with admission by natural draft)	Natural or forced-air admission. Large discharges. Low first cost, low maintenance cost.	Possible power loss and adverse effects on turbine performance. Restricted to sites with hydroplants.
Venturi tubes	2-3 lb/kwhr	Natural or forced-air admission.	Head loss. Small discharges.
Cascades	Determined from empirical formula (Low, see Table 4).	Maintenance free. Often associated with energy dissipation. Large discharges. No auxiliary equipment required.	Head loss may not be allowable. High first cost. Low transfer efficiency.
U-tubes	1-5 lb/kwhr	Natural or forced air admission. Low maintenance cost. High surface transfer, longer contact time, increased deficit due to pressurization. Can be used in channel.	Not yet proven for large discharges. Possible plugging with debris or ice.
Hydraulic guns	≈2 lb/kwhr	Efficient mixing, high surface currents, surface boil.	Primarily for mixing. Large bubble size, low transfer efficiency.
Pressure injection	No data available.		Small volumes
Fixed-cone valves	No power use or loss is involved.	Associated with required energy dissipation. Large volumes. No auxiliary equipment required.	Requires reservoir releases, which may not be possible.
Mechanical pump mixing	< 1 lb/kwhr	Simple equipment. Minimal maintenance.	Primarily for mixing. Low transfer efficiency. Verified only for relatively small volumes.
Hypolimnion reaeration and mixing	> 2 lb/kwhr	Allows stratification to remain undisturbed.	Relatively low transfer efficiency.
Molecular oxygen	14-55 percent	Can be used with various types of contact devices. High transfer efficiency. No dissolved nitrogen.	High cost of molecular oxygen.

Table 3 [From Ref (T-15)]

ANNUAL COSTS OF REAERATION*

Type of cost	Cost for diffused-air aeration ($)	Cost for turbine aeration ($)	Cost for cascade aeration ($)	Cost for mechanical aeration ($)
Capital cost	39,000	3,000	30,000	50,000
Per year	3,130	240	2,400	4,000
Annual operating cost	5,150	2,570	–	4,500
TOTAL	8,280	2,810	2,400	8,500

*Conditions for computation are: 10,000 lb oxygen/day/1,000 cfs (16 kg/day/100 cu m/sec) or 1.86 mg/l, for 90 days.

Table 4

COSTS OF APPLIED AERATION SYSTEMS

	Cascade (weir)	Air hoses (diffusers) Baldeney	Air pipes (diffusers) Lippe	Reservoir circulation	U-tube aerator	Turbine injection system Baldeney	Floating aerator	Turbo oxyder
Oxygenation capacity* (kg/hr)	0.88	28	22	16	4.1	120	41	13
Capital costs (DM)[1]	5,000	66,000	110,000	15,000	16,000	34,000	95,000	44,000
(year of construction)	(1965)	(1965)	(1965)	(1964)	(1958)	(1967)	(1965)	(1967)
Relative capital costs* ($DM/kg\ O_2/hr$)	5,700	2,360	5,000	940	4,000	283	2,300	3,280
Energy consumption* ($kwhr/kg\ O_2$)	0.85 (gravity flow)	***6.60	3.45	2.40	0.67 (gravity flow)	0.98	1.52	2.0
Total costs** ($DM/kg\ O_2$)	0.87 (gravity flow)	0.99	1.05	0.37	0.62 (gravity flow)	0.14	0.51	0.65
Reference	Bock and Schmidt [2]1965	Imhoff 1968 (I-5)	Londong 1967 (L-16)	Bernhardt 1963 and 1967 (B-15)	Bruijn and Tuinzaad 1958 (B-28)	Imhoff 1968 (I-5)	Imhoff 1968 (I-5)	–

[1] 4DM ≈ $1.00.
[2] Exact reference unknown.
*With 50 percent DO deficit.
**With 50 percent DO deficit, operating 30 days per year, 10-year life, and 0.10 DM/kwhr.
***Due to local conditions compressed air with 4.5 kg/cm^2 is used.

in cracks and crevices of construction materials, as explained by Johnson (J-9).

Tullis and Skinner (T-31), in a discussion of cavitation in valves, suggest three possible solutions for controlling cavitation:

1. Eliminating the nuclei or reducing their size.

2. Eliminating the pressure recovery which causes collapse of the cavities.

3. Eliminating the low-pressure zones in which the nuclei grow into vapor cavities.

The third solution is practical and has been used extensively for controlling cavitation in gates and valves, on turbine runners, and in high-velocity chutes and free tunnels. Cavitation is controlled by placing air in the low-pressure zone to raise the pressure above that required for growth of the cavities. Also, cavitation damage is reduced in the pressure recovery zone because of the presence of free air to cushion the effects of cavity collapse.

The preceding discussion leads to the conclusion that dissolved air has no effect on either cavitation or cavitation damage. However, it seems to the writer that the presence of dissolved air could lead to the presence of free air because of dissolution in low-pressure areas of the flow, as in "pseudo-cavitation." Whether this free air would provide protection is not clear. Therefore, it could be concluded that the amount of dissolved air and the conditions in which it exists would determine whether it would be beneficial or deleterious.

Dijkman and Vrengdenhil (D-9) studied the effect of dissolved gas on water-column separation. They assumed that the gas comes out of solution and collects in a single cavity at the top of the pipeline. Upon an increase in pressure, that cavity compresses or collapses. Their mathematical analysis predicts that, in the presence of dissolved gas, the pressure rise after compression of the cavity is lower than that for water without dissolved gas.

Panaiotti (P-2), in experiments on a cylindrical profile for application to problems of cavitation in pumps, found that variations in gas content of the water had no practical effect on cavitation.

Velocity and discharge control.—Reference (T-3) describes the use of a diffused air curtain for controlling the velocity of flow leaving a treatment plant grit removal chamber. Such an arrangement can have the dual purpose of reaeration and discharge control.

Removal of suspended matter.—Diffused air is used in sewage treatment for the removal of grit (A-2). The air is used to scour organic material from the grit, thus allowing the heavier grit to sink to the floor of the basin for removal. Also, a flotation process is used in which minute air bubbles are used to float suspended solids to the surface (E-10). The liquid is first supersaturated with air, then the pressure is reduced to produce the required small bubbles of free air. A similar process might have application in hydraulic engineering for removal of suspended sediments or other undesirable materials (S-11, S-12).

Fish control.—Curtains of diffused air have been used for controlling the movement of fish in the vicinity of separation facilities and fish ladders.

Ice control.—Diffused air has been used for some time to prevent ice formation in reservoirs (H-9, L-1, S-17). This is essentially a mixing application, in which warmer water is circulated from the bottom of a body of water to the surface during subfreezing air temperatures.

Control of surface pollutants.—The use of air curtains has been proposed for use in blocking the movement of surface pollutants, such as oil slicks (G-10).

Evaporation control.—Streif (S-37) proposed using compressed air to bring cold reservoir bottom waters to the surface, thus reducing evaporation losses. A measurable reduction in evaporation is reported by Koberg (K-18).

INSTRUMENTATION

The Winkler method (-2, H-21) is commonly used for laboratory analysis of dissolved oxygen. Within the past several years, electronic instrumentation has become available for this purpose. As pointed out by Wood (W-25), sensors have the advantages of (1) elimination of preparation and standardization of reagent solution, (2) reduced analysis time, (3) a less tedious method, and (4) excellent correlation with the Winkler method. A wide variety of sensors is available from a number of manufacturers. However, the reader should be cautioned that experience to date has shown that electronic equipment may not maintain calibration over a period of a few days.

RESEARCH NEEDS

Reported Research

The review has indicated considerable past research activity in:

- Natural reaeration in streams, reservoirs, and estuaries, including dispersion in streams
- Oxygen depletion by organic decay and nitrification
- Design and performance of diffusers and mechanical aerators for waste treatment applications
- Bubble dynamics
- Mathematical simulation of reaeration and oxygen depletion

Some research has been done concerning:

- Use of diffusers, mechanical aerators, and other devices for reaerating large volumes of water such as for in-stream reaeration and reservoir reaeration and mixing
- Use of molecular oxygen
- Comparative costs of reaeration methods and devices
- Reaeration efficiency of turbine injection
- Effects of air injection on turbine performance
- Air injection for cavitation control, velocity and discharge control, removal of suspended matter, and other miscellaneous applications
- Evaluation of outlet control valves for reaeration capability
- Reoxygenation by photosynthesis
- Reaeration at cascades
- Use of radioactive tracers in field studies
- Development of instrumentation
- Development of U-tube aeration
- Turbulent mixing in surface aeration

Current Research Activity

Research, as yet unreported, is currently underway in several areas including:

- Natural stream reaeration
- Reaeration by photosynthesis
- Mathematical simulation
- Induced mixing by air
- Field evaluations of reaeration
- Use of molecular oxygen, including liquid oxygen
- Oxygen transfer to water droplets
- Flow surface protection against cavitation
- Diffusion away from free surface
- Nitrogen and ammonia removal
- Design of aeration devices
- Use of radioactive gas tracers in field studies
- Foam separation of suspended materials
- Effects of audio vibrations on oxygen transfer rates
- Ice control
- Aeration with recycled foam
- Concentration of streamflow to mechanical aerators
- Stream oxygen balance
- Removal of metals from acid mine discharge by foam fractionation
- Spraying water into pressurized tank of pure oxygen or air
- Study of nucleus formation in cavitation
- Influence of surface mixing downstream from surface aerators
- Economics of water quality management programs, including reaeration
- Reaeration efficiency of Howell-Bunger valves
- Precipitation of metallic elements

Suggestions for Future Research

The review has indicated a need for new or additional research in the following areas, in order of their importance:

a. Correlation of the reaeration rate constant, k_2, with flow parameters. A fresh approach appears to be needed.

b. Development of a method to determine true efficiency of reaeration devices, perhaps by assignment of a k_2 for each device. Elimination or isolation of factors which modify experimental measurements and cause inaccurate evaluation of actual amount of oxygen added.

c. Comparative economic analyses of aeration methods and devices. Development of guidelines to allow comparisons on the basis of cost per unit of dissolved oxygen increase.

d. Development of new methods and devices for reaeration. Testing of promising methods and devices developed by others. Continuing review of research activity by others.

e. Additional field testing and evaluation of injection of air or oxygen into turbines.

f. Evaluation of energy dissipators, gates, and valves for reaeration capability. Field testing of prototype structures.

g. Determination of modifications for existing structures to improve reaeration characteristics. Laboratory and field tests.

h. Study of the effects of dissolved air on cavitation on high-velocity flow surfaces.

i. Development of miscellaneous engineering uses of injection of air into water.

GLOSSARY OF TERMS

algae—a one-celled photosynthetic microscopic plant.

benthic—refers to the bottom of lakes and reservoirs.

biota—all the living organisms in a given region.

BOD—biochemical oxygen demand, amount of oxygen required for biological oxidation of organic matter.

diffusion—transport due to the difference between true convection and the time average of convection, movement of a species in a mixture from a point of higher concentration to a point of lower concentration.

diffusivity—molecular diffusion coefficient, time rate of diffusion.

dispersion—transport due to variations in longitudinal velocity in a cross section.

dissolved oxygen saturation deficit—the difference between the amount of dissolved oxygen present in a solution at a given temperature and the amount which would be present for a saturated condition at the same temperature.

dystrophic—lakes or reservoirs with very low lime content and very high humus content which often lack nutrients.

epilimnion—the upper layer of a stratified lake or reservoir, from the surface to the thermocline, usually mixed.

eutrophic—having an abundance of aquatic plant growth such as algae due to overenrichment with nutrients such as nitrogen and phosphorus.

hypolimnion—the bottom layer of a stratified lake or reservoir, from the thermocline to the bottom, isolated from surface influence.

isotropic turbulence—statistically independent of the orientation and location of the coordinate axes of velocity measurement.

molecular (tonnage) oxygen—pure oxygen, the molecular state, O_2.

nitrification—transformation of ammonia nitrogen to nitrates.

oligotrophic—lakes or reservoirs with a small supply of nutrients.

oxygen sag—a curve which depicts the concentration of dissolved oxygen along a stream.

photosynthesis—the natural process by which light and chlorophyll are used by plants to synthesize carbohydrates from CO_2 and water; oxygen is produced in the process.

respiration—process by which living organisms take in oxygen from air or water.

sparge ring—a circular diffuser for the introduction of air into mechanical aerators or hydraulic turbines.

stratification—a vertical variation in temperature, dissolved oxygen, chemicals, turbidity, etc., in a stream, lake, or reservoir.

DEFINITIONS OF MATHEMATICAL TERMS

a	=	coefficient of water quality in weir equations, dimensionless
a	=	ratio of bubble or water surface area to liquid volume, L^{-1}
A	=	bubble or water surface area, L^2
A'	=	molecular collision factor, T^{-1}
b	=	coefficient of weir configuration, dimensionless
b	=	film thickness, L
C, c	=	a constant
C	=	concentration, M/L^3
C_o	=	initial concentration, M/L^3
C_s	=	saturation concentration or solubility, M/L^3
C_t	=	concentration at time t, M/L^3
γ	=	specific weight, M/L^3
d_e	=	equivalent bubble diameter, L
D	=	oxygen deficit, M/L^3
D'	=	bubble diameter, L
D_L	=	longitudinal mixing coefficient, L^2/T
Dm, D_{AB}	=	molecular diffusion coefficient, L^2/T
D_o	=	initial oxygen deficit, M/L^3
E	=	rate of energy dissipation per unit mass, L^2/T^3
E	=	diffuser efficiency, percent
E_a	=	energy required by molecule to be included in reaction, ML^2/T^3 mole
f	=	friction factor, dimensionless
g	=	acceleration of gravity, L/T^2
G_s	=	airflow, L^3/T
h	=	weir free fall height, L
H	=	depth of flow, L
θ	=	temperature correction constant, dimensionless
k	=	reaction rate, T^{-1}
K_1 or k_1	=	BOD rate constant, T^{-1}
K_2 or k_2	=	reaeration rate constant, T^{-1}
K_d	=	an exponent, dimensionless
K_L	=	liquid-film coefficient, L/T
K_La	=	overall transfer coefficient, T^{-1}
L	=	liquid film thickness, L
L	=	BOD, M/L^3
La	=	initial BOD, M/L^3
m	=	mass, M
n	=	exponent, function of bubble size, dimensionless
n	=	rate of mass transfer, M/L^2–T
N	=	mechanical aeration efficiency, M/LFT
P	=	power use, LF
Pe	=	Peclet number, dimensionless
q	=	transfer rate, M/T
r	=	ratio of upstream deficit to downstream deficit for weirs, dimensionless
r	=	rate of renewal of liquid film, T^{-1}
R	=	universal gas constant, ML^2/T^2 per mole–^oK
Re	=	bubble Reynolds number, dimensionless
ρ	=	mass density, M/L^3
Sc	=	Schmidt number, dimensionless
Se	=	energy gradient, dimensionless
Sh	=	Sherwood number, dimensionless
SR	=	oxygen supply rate, M/T

DEFINITIONS OF MATHEMATICAL TERMS—Continued

t	=	time, T
t'	=	time of one cycle of absorption and mixing, T
t_{exp}	=	time of bubble exposure, T
T	=	temperature, degrees
TR	=	oxygen transfer rate, M/T
$\bar{u}$	=	average velocity, L/T
v	=	bubble or liquid velocity, L/T
V	=	liquid volume, L^3
v_t	=	terminal bubble velocity, L/T
ν	=	kinematic viscosity, L^2/T
W	=	system capacity, L^3
W	=	mass fraction, dimensionless
x	=	distance, L

BIBLIOGRAPHY PREFACE

This bibliography represents a sincere attempt by the writer to prepare a comprehensive list of references on the subject of reaeration. Undoubtedly, some important references have been inadvertently omitted, while some references of questionable value have been included.

Not all of the references were available to the writer for personal review. In some cases, summaries by others were studied and, where appropriate, the information contained therein was included in this report.

The subject index which follows the bibliography was based on abstracts, annotations, or titles of the references wherever possible.

BIBLIOGRAPHY

-1 Anon
COMPRESSED AIR HANDBOOK
Compressed Air and Gas Institute New York N Y 1947
Contains data on characteristics of air blowers

EQUIPMENT
diffusers

-2 Anon
STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER
11th Edition American Public Health Assoc New York N Y 1960

DO ANALYSIS

-3 Anon
AERATION OF LARGE VOLUMES OF WATER
Water and Waste Treatment J (Brit) v7 1960 p 508
Water Pollution Abstracts (Brit) v 34 1961 p 37
Describes in very general terms a system which injects compressed air into flow pumped from thermal power station cooling water discharge. Supersaturated flow is returned to main flow where surplus air comes out of solution for reaeration of the entire flow

EQUIPMENT
reservoirs
pressure injection

-4 Anon
NEW LIFE FOR POLLUTED SWEDISH LAKES
Water Waste Treatment J v 8 1960 p 65
Water Pollution Abstracts v 40 1961 p 941
Reports on using compressed air to destratify polluted Swedish lakes; in 3 weeks oxygen content increased from 0 to 57 percent, new plant life appeared, and the original temperature differential of 12° C disappeared

EQUIPMENT
reservoirs
diffusers

-5 Anon
FLOATING PUMP FIGHTS POLLUTION
Chem Eng v 69 n 17 1962 p 70

EQUIPMENT
reservoirs
pumps

-6 Anon
SWEETENING A SMELLY RIVER WITH OXYGEN
Eng News-Record v 169 n 2 1962 p 42

EQUIPMENT
streams

-7 Anon
STREAMFLOW REGULATION FOR QUALITY CONTROL
Robert A Taft Sanitary Eng Center Cincinnati Ohio Apr 3-5 1963

BASIC STUDIES
streams
experimental

-8 Anon
REVIEW OF LITERATURE OF 1963-1968 ON WASTEWATER AND WATER POLLUTION CONTROL
Water Pollution Control Federal J
v 36 n 7 Jul 1964 p 791
v 37 n 7 Jul 1965 p 887
v 38 n 7 Jul 1966 p 1049
v 39 n 7 Jul 1967 p 1049
v 40 n 6 Jun 1968 p 897
v 41 n 6 Jun 1969 p 873
Reviews and separates bibliographies of literature on water pollution; including stream self-purification in relation to oxygen sag

GENERAL
reviews

-9 Anon
LAGOON AERATION SYSTEM BUBBLES AWAY WASTE TREATMENT PROBLEMS
World Construction v 20 n 3 Mar 1967 p 19-21

Air-Aqua grid system, originally designed for small community treatment plants, was installed in lagoons of Regina, Saskatchewan, plant to eliminate odor problems; in action and performance this system can be compared to fast-moving stream where rolling motion brings oxygen down to bottom water and also brings oxygen-deficient up to surface; installation and general details of system; 30 blowers with 30-hp motors provide air; blowers are mounted on 11-ft concrete piers to prevent movement in winter (EI 1967)

EQUIPMENT
waste treatment
diffusers

-10 Anon
OXYGEN SPEEDS UP WASTE TREATMENT
Ind Eng Chem v 61 n 2, 5–6

The use of oxygen instead of air to gain maximal efficiency from the activated-sludge process is discussed. Union Carbide is to run a full-scale test for their process at the Batavia, N.Y., sewage works. The same influent stream will feed a normal aeration tank and an aeration tank supplied with oxygen, so that a direct comparison of performance can be made (Publ Wks N Y 1969 v 100 n 3 p 118) (WPA 1625 Aug 1969)

EQUIPMENT
waste treatment
molecular oxygen

-11 Anon
SILICONE RUBBER FOR MEMBRANE LUNG
Nature v 224 n 5217 Oct 1969 p 301-302

Reports the development of silicone rubber membranes said to have potential applications in oxygenating blood in heart-lung machines, underwater breathing apparatus, and water desalting; membrane has high permeability to gases with a selective permeability to carbon dioxide in solution 12 times greater than for oxygen

EQUIPMENT
misc equipment

A

A-1 Adeney, W E Becker, H G
THE DETERMINATION OF THE RATE OF SOLUTION OF ATMOSPHERIC NITROGEN AND OXYGEN BY WATER
Philosophical Magazine s 6 v 38 n 225 Sep 1919; v 39 n 232 Apr 1920

BASIC STUDIES
experimental
reaeration

A-2 Albrecht, A E
AERATED GRIT OPERATION DESIGN AND CHAMBER
Water and Sewage Works v 114 n 9 Sep 1967 p 331-335

Experimental program established to determine satisfactory method for controlling grit chamber hydraulics; if properly designed, aerated grit chambers will exhibit certain advantages over conventional grit chambers; long, narrow chamber design, incorporating longitudinal baffle, was developed; this chamber design provides 95 percent removal of 60 mesh grit (specific gravity 2.6); organic matter content of this grit would be approximately 5 percent (EI 1968)

EQUIPMENT
waste treatment
misc uses

A-3 Albrecht, D
BELUFTUNG DES RUHRWASSERS AM WEHR SPILLENBURG
(Aeration of the Ruhr Water at Spillenburg Weir)
Die Wasserwirtschaft 1968 Heft 11 In German

EQUIPMENT
streams
cascades

A-4 Albrecht, Detlef
SCHATZUNG DER SAUERSTOFFZUFUHR WEHRE UND KASKADEN
(Aeration of Water by Weirs and Cascades)
Wasserwirtschaft v 59 n 11 Nov 1969 p 321-323

Discusses the use of cascades for artificial aeration and the increase in oxygen at existing weirs and cascades In German

EQUIPMENT
streams
cascades

A-5 Al-Saffar, Adnan Mustafa
EDDY DIFFUSION AND MASS TRANSFER IN OPEN-CHANNEL FLOW
PhD Thesis U of Calif Berkeley 1964

BASIC STUDIES
streams
experimental
reaeration

A-6 Amand, M T
PREDICTING DISSOLVED OXYGEN CONCENTRATION IN A LAKE COVERED WITH EVAPORATION SUPPRESSANT
J Water Pollution Control Federation v 40 n 11 Nov 1968 p R423-R433

Diffusion of oxygen from the atmosphere through a monomolecular film of a hexadecanol-octadecanol mixture was investigated under quiescent conditions. The study revealed that the oxygen-uptake rate of organisms in water can be measured and used to predict the lowest dissolved oxygen concentration in water during early morning hours when oxygen concentration is most critical. Oxygen-transfer rates in distilled water at 21^{o} and 36^{o} C treated with a monomolecular film were 74 and 84 percent, respectively, of the rates for untreated distilled water. Treated pond water containing 194 mg/l dissolved solids showed oxygen-transfer rates of 89.6 and 92.6 percent at 21^{o} and 36^{o} C, respectively, as compared with untreated pond water. An equation for the temperature dependance of rate coefficients for treated and untreated water is given. Theoretical and measured values for minimum dissolved oxygen agree closely

BASIC STUDIES
reservoirs
reaeration

A-7 Amberg, H R Cormack, L F Funk, W Rosenfeld, A S Blosser, R O
RE-AERATION OF STREAMS WITH MOLECULR OXYGEN
Ind Water Eng v 4 n 2 Feb 1967 p 15-20

Artificial stream aeration is a promising method for alleviating critically low dissolved oxygen levels in streams. Stream aeration using air has been studied and used widely, but no experimental work has been reported on the use of tonnage oxygen. Aeration efficiency with air is very poor as the saturation level is approached, and this problem can be overcome by using oxygen. Experiments on the feasibility of using oxygen were conducted at a power turbine at Willamette Falls, Oregon, by venting the turbine with air and oxygen. The first run was with air, and the second with oxygen. Another oxygen trial was made using a multiple-diffuser sparge ring encircling the turbine above the runner blade. Experimental procedures and results are discussed and oxygen stream aeration systems are compared on the bases of efficiencies, costs, and effect on turbine operation

EQUIPMENT
streams
turbine injection
molecular oxygen

A-8 Amberg, H R and others
STREAM REAERATION USING TONNAGE OXYGEN
presented to the Regional Meeting of the National Council for Stream Improvement Crown Zellerbach Corp Portland Oreg Sep 1967

Compared efficiency of injection of air or molecular oxygen above runner blade of Pelton turbine with single vent injection and sparge ring injection. Data on power loss and cost of oxygen are presented. Vibration of turbine resulting from injection is discussed

EQUIPMENT
streams
turbine injection
molecular oxygen

A-9 Amberg, H R Wise, D W Aspitarte, T R
AERATION OF STREAMS WITH AIR AND MOLECULAR OXYGEN
Tappi v 52 n 10 Oct 1969 pp 1866-71

Results are given on full-scale river aeration by two methods (a) release of oxygen into hydroelectric turbines, and (b) diffusion of gaseous oxygen into water under pressure. Oxygen is approximately five times as effective as an equal quantity of air in imparting dissolved oxygen to streams. The authors consider that provided the oxygen is procured at $30 per ton dissolved oxygen can be added to the water at a total cost of 3 to 4 cents per pound

EQUIPMENT
streams
turbine injection
diffusers
molecular oxygen

A-10 Ambuhl, H
THE PRACTICAL APPLICATION OF THE ELECTROCHEMICAL DETERMINATION OF OXYGEN IN WATER
Schweizerische Zeitschrift fur Hydrol v 22 Fasc 1 1960 p 23-29
Transl from German USBR No 614

A commercial limnological probe was developed for the remote simultaneous determination of temperature, oxygen, and conductivity by electrochemical methods. The fundamentals of electrochemical methods and technical details involved in the selection of instrumentation systems are discussed. Some basic features of the probe include: (1) cable coupling arrangement to make possible the use of cables of different lengths; (2) temperature measurements made with a thermistor sensor and an alternating-current-powered Wheatstone bridge; (3) simultaneous determination of resistivity and conductivity. Conductivity is measured directly by rearranging bridge members and measuring the reciprocal resistance. Conductivity may be measured continuously, but temperature effects must be compensated. Automatic temperature compensation is technically feasible, but is presently uneconomical; and (4) measurement of high and low oxygen contents. Low oxygen contents are determined by measuring only the diffusion currents at

DO ANALYSIS
instrumentation

the electrodes. High oxygen contents are determined potentiometrically by supplying an auxiliary voltage to the electrodes. The step-by-step operation of the instrument is covered in detail

A-11 Anderson, C A
AERATION RECOVERY OF LANOLIN FROM WOOL SCOUR LIQUOR
Textile Res J v 30 1960 p 51-57
Investigation of the aeration process has resulted in an improved design for a continuous recovery plant. On a pilot scale the design has permitted throughput rates about 2-1/2 times greater than previous designs, with equal recovery efficiencies. (Livengood-N C) W69-10286

EQUIPMENT
waste treatment

A-12 Angelino, H
HYDRODYNAMIQUE DES GROSSES BULLES DANS LES LIQUIDES VISQUEUX
Chem Eng Sci v 21 n 6-7 Jun-Jul 1966 p 541-550
Hydrodynamics of large bubbles in viscous liquids; with four columns of diameter between 10 and 40 cm, it has been possible to make systematic study of rising motion of air bubbles of various volume through liquids of different viscosity; evolution of bubble's shape with increasing volume is studied, and relation between frontal diameter and volume is proposed; study is made of influence upon velocity of ascension of proximity of walls. 28 refs. In French (EI 1967)

EQUIPMENT
diffusers

A-13 Aris, R
ON THE DISPERSION OF A SOLUTE IN A FLUID FLOWING THROUGH A TUBE
Proc Royal Society of London v 235A 1956 p 67

BASIC STUDIES
experimental
reaeration

B

B-1 Baars, J K Muskat, J
OXYGENATION OF WATER BY BLADED ROTORS
J and Proc Inst Sewage Purif (Brit) pt 5 1963 p 454

EQUIPMENT
waste treatment
mechanical
aerators

B-2 Bain, Richard C Jr
PREDICTING DO VARIATIONS CAUSED BY ALGAE
Proc ASCE V 94 n SA 5 1968 p 867-881

Eutrophic environments are often dominated by planktonic algal populations (phytoplankton) which can cause diurnal variations in DO concentrations through respiratory activity and photosynthesis. Photosynthetic oxygenation and respiratory deoxygenation rates of estuarine phytoplankton were measured at various standing crop (chlorophyll) levels. Oxygen production and consumption rates for actively growing phytoplankton populations were related to standing crop at 20^{o} C and nonlimiting light. Variations in algal photosynthetic production rate, as related to light adaption, age of cells, nutrition, temperature, and algal type, are considered. The Streeter-Phelps equation was modified to include phytoplankton production and respiration rates in formulations designed to predict DO concentrations over a 24-hr period. An example is given and the resulting predictions are compared with field measurements from a tidal reach of the San Joaquin River, Calif

BASIC STUDIES
streams
experimental
photosynthesis
respiration

B-3 Barkov, N K
VPUSK SZHATOGO VOZDUKHA V ZONU RABOCHEGO KOLESA PRI NESPOKOINOM REZHIME RABOTY RADIAL'NO-OSEVOI GIDROTURBINY
Energomashinostroenie n 4 Apr 1968 p 39-40

Injection of compressed air into runner section during perturbed operation of radial-axial hydraulic turbine; results are reported of experiments performed on turbine provided with system of 12 pipes, 50-mm diameter radially disposed on turbine hood and connected to 49-cu-m air receiver; compressed air at 5 to 8 atm pressure was injected under hood; ratio between air and water flow rate was 0.0462; besides effecting quiet operation of turbine, air injection reduced considerably blade area subject to cavitating erosion and increased service life of blades. In Russian (EI 1968)

EQUIPMENT
streams
turbine injection

B-4 Barnhart, Edwin L
TRANSFER OF OXYGEN IN AQUEOUS SOLUTIONS
Proc ASCE v 95 n SA 3 Jun 1969 p 645-661

The paper reports the results of studies which describe the influence of geometry and temperature on the liquid film coefficient, K_L, and the mass transfer coefficient, K_La, for the transfer of oxygen from air bubbles rising in a liquid. It is shown that the liquid film coefficient is related to the total drag force operating at the liquid gas interface. The influence of several surface active agents on K_La and K_L are reported. The study indicates that at low concentrations, the principle influence of surface active agents is their effect on the bubble size and rate of rise

BASIC STUDIES
experimental
reaeration

B-5 Barrett, M J Gameson, A L H Ogden, C G
AERATION STUDIES AT FOUR WEIR SYSTEMS
Water and Water Eng (Brit) v 64 1960 p 407

Data from four weir systems with discharges from 1 to 500 mgd were used to verify an empirically derived predictive equation. Discusses effect of weir configuration (steps vs free weirs)

EQUIPMENT
streams
cascades

B-6 Bartsch, A F
ALGAE AS A SOURCE OF OXYGEN IN WASTE TREATMENT
Sewage and Ind Wastes v 33 1961 p 239-249
BASIC STUDIES
experimental
photosynthesis

B-7 Batchelor, G K
TURBULENT DIFFUSION
Lecture Series No. 4 U of Maryland College Park 1960
BASIC STUDIES

B-8 Bayley, R W Wyatt, K
AERATION OF EFFLUENTS BY VENTURI TUBE
Water and Waste Treatment J Nov-Dec 1961
EQUIPMENT
Venturis

Laboratory tests show effective aeration can be achieved by a Venturi tube by air bubbles introduced through holes in the throat of the Venturi; however predictions on performance of a full-size unit are not made because of other important factors

B-9 Beck, A J
DIFFUSER PLATE STUDIES
Sewage Works J 8 1936 p 22
EQUIPMENT
waste treatment
diffusers

B-10 Becker, H G
MECHANISM OF ABSORPTION OF MODERATELY SOLUBLE GASES IN WATER
Ind Eng Chem v 16 1924 p 1220
BASIC STUDIES
reaeration

B-11 Bella, D A Dobbins, W E
DIFFERENCE MODELING OF STREAM POLLUTION
Proc ASCE v 94 n SA 5 1968 p 995
BASIC STUDIES
streams
theoretical

B-12 Benjes, Henry H Jr McKinney, Ross E
SPECIFYING AND EVALUATING AERATION EQUIPMENT
Proc ASCE v 93 n SA 6 Dec 1967 p 55-64
EQUIPMENT
waste treatment

One of the most complex aspects of designing a modern activated sludge waste water treatment system is concerned with the selection of optimum aeration equipment. A performance evaluation for initial operating conditions has been developed which can be extrapolated to the design operating conditions. The performance evaluation requires determination of operating air-flow rates, temperature, mixed liquor suspended solids, oxygen demand rates, and dissolved oxygen. The application of the performance evaluation technique to the aeration equipment furnished for the Grand Island, Nebr., activated sludge plant is described. The experience obtained from the performance evaluation at Grand Island has pointed to certain necessary refinements in the evaluation technique. A sample aeration equipment performance specification is appended incorporating these refinements

B-13 Bennett, G F Kempe, L L
OXYGEN TRANSFER IN BIOLOGICAL SYSTEMS
PURDUE U—Eng Extension Ser v 118 1965 p 435-449
BASIC STUDIES
waste treatment
experimental
reaeration

Oxygen transfer rate in unsparged, but agitated system is shown less than rate in system that is both sparged and agitated simultaneously; differences between these measurements increase as gas-liquid interface or partial pressure of oxygen in gas is increased; data suggest two parallel paths for oxygen transfer from air to cell; in unsparged liquid, microorganism has available only oxygen dissolved in liquid; in sparged system, some cells adsorb on air bubbles, or air bubbles adsorb on cells; by this process, some resistance to oxygen transfer is promoted. 43 refs (EI 1967)

B-14 Bernhart, A P
POWER OF SELF-PURIFICATION IN RIVERS EXEMPLIFIED BY TORONTO'S DON RIVER
Eng J v 48 n 2 Feb 1965 p 31-34
Water recovery in upper Don after pollution shock is indicated by fast reduction BOD, phosphates and coli bacteria as well as by increase in dissolved oxygen; lighter water color, improved conditions of streambed and reappearance of higher organisms also indicate strong self-purification (EI 1965)

BASIC STUDIES
streams
experimental
reaeration

B-15 Bernhardt, H
AERATION OF WAHNBACH RESERVOIR WITHOUT CHANGING TEMPERATURE PROFILE
American Water Works Assoc J v 59 n 8 Aug 1967 p 943-964
Results of aeration tests on reservoir in Siegburg, West Germany, which contains 33,740 acre-ft, has maximum depth of 141 ft, with its surface 410 ft above sea level, are reported; tests showed among other things that aeration and mixing of impoundment are feasible and that complete destratification by diffused air bubble method and aeration of hypolimnion only both had favorable effect on water quality, but aeration of hypolimnion had additional advantage of preserving quantity of cold water for use as drinking water. 26 refs (EI 1967)

EQUIPMENT
reservoirs
diffusers

B-16 Beuthe, C G
IMPROVEMENTS IN FINE-BUBBLE AERATION FROM THE STANDPOINTS OF TECHNIQUE AND OPERATION
Water Pollution Control London v 68 1969 p 51-58
The mathematical relations for activated-sludge tanks operating as homogeneous and heterogeneous reactors and with constant hydraulic loading (see Water Pollution Abstracts v 41 n 1649 1968) were tested by observing the performance of two plants equipped with tubular diffusers. The results indicate that for maximal efficiency an aeration tank should have longitudinal flow, constant sludge loading, and tapered aeration. The advantages of fine-bubble aeration by tubular diffusers over surface aeration are indicated (WPA 1382 Jul 1969)

EQUIPMENT
waste treatment
diffusers

B-17 Bewtra, J K Nicholas, W R
BASIC VARIABLES OF OXYGENATION FROM DIFFUSED AIR AERATION TANKS
presented at the 17th Annual Purdue Ind Wastes Conf 1962

EQUIPMENT
waste treatment
diffusers

B-18 Bewtra, J K Nicholas, W R
OXYGENATION FROM DIFFUSED AIR IN AERATION TANKS
Water Pollution Control Federation J v 36 n 10 Oct 1964 p 1195-1224
Oxygen transfer studies conducted in 4-ft-long section of full-scale aeration tank at Philip F. Morgan Sanitary Engineering Laboratory, State University of Iowa; variables of oxygen transfer from air to water were studied; variables are presented mathematically and their relative importance is discussed; development of oxygen transfer equation; effect of diffuser submergence on oxygenation; effect of aeration tank width on oxygenation. 24 refs (EI 1965)

EQUIPMENT
waste treatment
diffusers

B—Continued

B-19 Bird, R B Stewart, W E Lightfoot, E N
TRANSPORT PHENOMENA
John Wiley and Sons, Inc N Y 1960

GENERAL

B-20 Bischofsberger Tofaute
POROUS PLASTICS FOR FINE BUBBLE AERATION OF WASTE WATERS
Tech Scientific Reports of the Ems Federation and the Lippe Assoc v 6 1964 p 26-43

EQUIPMENT
waste treatment
diffusers

B-21 Black, S A
SUPPLEMENTARY AERATION OF WASTE STABILIZATION PONDS FOR INDUSTRIAL WASTES
Water and Pollution Control v 105 n 1 Jan 1968 p 30-31

Raw industrial and domestic wastes were contained in stabilization pond for treatment and used for operational and performance data collection and evaluation when aerated by surface mechanical-aeration device; method of study and results obtained; steps are suggested for effective treatment of waste (EI 1967)

EQUIPMENT
waste treatment
mechanical aerators

B-22 Black, S A
CAN AERATION PONDS POLISH SEWAGE PLANT EFFLUENT
Water and Pollution Control v 105 n 6 Jun 1967 p 38, 40, 42

Effluent polishing pilot plant study was performed to evaluate polishing processes suitable to provide additional treatment to secondary treatment plant effluents in Ontario; pilot plant consisted of aeration pond and settling lagoon coupled in series; from study it was concluded that if certain design and operational requirements are met, effluent with BOD and suspended solids content not exceeding 8 ppm may be maintained by aeration pond; aeration pond should be followed by settling lagoon of 1 to 2 days' retention to raise dissolved oxygen of effluent to 4 ppm before its introduction to receiving stream (EI 1967)

EQUIPMENT
waste treatment

B-23 Blain, W A McDonnel, A J
REAERATION MEASUREMENTS IN A EUTROPHIC STREAM
Proc 22nd Int Waste Conf Purdue U Ext Ser 129 1968 p 1044

BASIC STUDIES
streams
experimental
reaeration

B-24 Blodgett, J H
AIR DIFFUSION WITH SARAN-WRAPPED TUBES
Sewage and Ind Wastes v 22 1950 p 1290

EQUIPMENT
waste treatment
diffusers

B-25 Bohnke, B
EFFECTS OF ORGANIC WASTEWATER AND COOLING WATER ON SELF-PURIFICATION OF WATERS
Proc 22nd Ind Waste Conf Purdue U Ext Ser 129 1968 p 752

BASIC STUDIES
streams
experimental
reaeration

B-26 Browning, Jon E
O_2 & O_3—RX FOR POLLUTION?
Chem Eng v 77 n 4 Feb 23 1970 p 46-48

New oxygenation and ozonation processes look promising for waste treatment and water purification; gives brief descriptions and some costs for Linde's oxygenation municipal sewage treatment plant at Ratavia, N. Y.; Air Reduction Co.'s ozone system for tertiary waste treatment; Crown

EQUIPMENT
waste treatment

Zellerbach's oxygenation system for a paper mill at Bogalusa, La.; and Container Corp.'s oxygenation of paper mill waste water at Brewton, Ala

B-27 Bryan, J G
IMPROVEMENT IN THE QUALITY OF RESERVOIR DISCHARGES THROUGH RESERVOIR MIXING AND AERATION
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 317-344
Describes the aerohydraulic gun and the aeration capacity and mixing produced by these guns. Examples of practical applications are given at Blelham Tarn, Inniscarra Reservoir, and Lock Turret Reservoir

EQUIPMENT
reservoirs
hydraulic guns

B-28 Bruijn, Jacob Tuinzaad, Hendrick
THE RELATIONSHIP BETWEEN DEPTH OF U-TUBES AND THE AERATION PROCESS
J American Water Works Assoc Jul 1958 p 879
Reports original development of U-tube oxygenation method and describes prototype installation

EQUIPMENT
streams
U-tubes

B-29 Bryson, R A Sumoi, V E
MIDSUMMER RENEWAL OF OXYGEN WITHIN THE HYPOLIMNION
J Marine Research v 10 1951 p 263-269

EQUIPMENT
reservoirs

B-30 Bulicek, J
ARTIFICIAL AERATION OF WATER IN THE MOLDAU IMPOUNDING RESERVOIRS AND IN CZECHOSLOVAKIA
Vodn Hospod v 9 1957 Czech
Wasserwirtschaft (Stuttgart) v 49 1959 p 25
Water Pollution Abstracts v 40 1960 p 1910
Describes an unsuccessful attempt to save fish by aerating water with paddle-wheel steamers

EQUIPMENT
streams
mechanical aerators

B-31 Burdick, M E
OPEN WATER IN WINTER
Wisconsin Conservation Bull v 24 1959 p 21
Reports on compressed air mixing of lakes to prevent winterkill of fish when the lake freezes over and cuts off the oxygen supply

EQUIPMENT
reservoirs
diffusers
misc uses

B-32 Burns, O B Jr Eckenfelder, W W Jr
AERATION IMPROVEMENTS AND ADAPTION OF COOLING TOWER TO ACTIVATED SLUDGE PLANT
Tappi v 48 n 11 Nov 1965 p 96A-99A
Problems associated with high temperature of waste effluent during summer and inadequate aeration capacity were solved by installation of counter-flow cooling tower and by modification of aeration tanks; by these changes, plant overall efficiency is maintained in range from 85 to 90 percent and average final effluent BOD is improved from 43.9 to 25.4 ppm (EI 1966)

EQUIPMENT
waste treatment

B-33 Burns, O B Jr St. John, J P O'Connor, D J
PILOT MECHANICAL AERATION STUDIES OF THE JACKSON RIVER IN COVINGTON, VIRGINIA
Proc 21st Ind Waste Conf Purdue U Ext Ser 121 1966 p 799

Describes use of plate-type surface aerator placed at location of minimum DO in stream. Efficiency of 2.15 lb oxygen/hp-hr for 100-percent DO deficit. Discussion of paper describes German use of floating surface aerators (1.75 lb oxygen/kwhr at 50-percent deficit), diffuser (5-percent efficiency at 50-percent deficit), and injection above runner of hydroturbine (efficiency not given)

EQUIPMENT
streams
mechanical aerators
diffusers
turbine injection

B-34 Burrows, M G
INHIBITION OF AERATION PROCESS: QUANTITATIVE ASSESSMENT OF SOME TOXIC MATERIALS
Water Pollution Control v 68 n 4 1969 p 457

The cost of treating industrial effluents containing inhibitors can be evaluated by using a laboratory activated sludge apparatus consisting of a set of aeration tanks into which a 30:20 effluent is added as control and, in other tanks, settled sewage containing 2 mg/l of various inhibitors fed. After daily aeration cycles had been carried out for a week, the supernatant liquor was sampled and analyzed and performance evaluated in each case. The inhibitory effects of various metals and cyanide were tabulated

BASIC STUDIES
waste treatment
experimental

B-35 Butts, T A Schnepper, D H
OXYGEN ABSORPTION IN STREAMS
Water and Sewage Works v 114 1967 p 385

BASIC STUDIES
streams
experimental
reaeration

C

C-1 Cable, M
DISSOLVING OF STATIONARY GAS BUBBLES IN LIQUID
Chem Eng Sci v 22 n 11 Nov 1967 p 1393-1398
Theoretical interpretation of dissolving of gas bubbles in liquids has usually been based on model which ignores effect of motion of liquid on concentration field and predicts linear relation between square of size and time; experimental data plotted in this way often show decrease in slope; theoretical results are now available which take radial motion of liquid into account; these show that decrease in slope is in accordance with theory; some experimental results are in good agreement with theory, but others show marked deviations; possible reasons for these deviations are discussed. 22 refs (EI 1968)

BASIC STUDIES
bubbles
theoretical
experimental
reaeration

C-2 Cadwallader, E Thomas McDonnell, J Archie
A MULTIVARIATE ANALYSIS OF REAERATION DATA
Water Research Pergamon Press v 3 1969 p 731-742
Describes the application of the statistical technique of multivariate analysis to two sets of prototype reaeration data and one set of laboratory data, and to a combined set. The exchange coefficient was found to be consistently defined by the rate of energy dissipation (E) for values of E $>$ 0.001 ft^2/sec^3. For E $<$ 0.001 factors related to molecular diffusion are controlling

BASIC STUDIES
streams
experimental
reaeration

C-3 Camp, Thomas R
FIELD ESTIMATES OF OXYGEN BALANCE PARAMETERS
Proc ASCE v 91 n SA 5 Oct 1965 p 1-17
Field studies of oxygen balance in Merrimack River, Mass; Streeter-Phelps equations, extended to include addition of BOD from bottom deposits, removal of BOD by settling, production of dissolved oxygen by photosynthesis, and longitudinal mixing by tides, indicated 50 to 80 percent of BOD by settling and approximately two-thirds of oxygen furnished by algae in photosynthesis; atmospheric reaeration rate constant was found to be considerably less than expected; algae was found to be essential to pollution control

BASIC STUDIES
streams
experimental
reaeration
photosynthesis

C-4 Carver, C E Jr
ABSORPTION OF OXYGEN IN BUBBLE AERATION
Biological Treatment of Sewage and Ind Wastes v 1 1955

EQUIPMENT
waste treatment
diffusers

C-5 Carver, C E Jr
OXYGEN TRANSFER FROM FALLING WATER DROPLETS
Proc ASCE v 95 n SA 2 Apr 1969 p 239-251
Overall oxygen transfer coefficients are obtained for deaerated water droplets falling freely through the atmosphere with and without 50 ppm of a synthetic detergent. Drop distances ranged from 0 to 13 ft, and droplet surface areas varied from 0.47 to 0.55 cm^2. Transfer coefficients are found to decrease somewhat with increasing droplet size, becoming independent of droplet size above 6.0 ppm of DO. With detergent present, the coefficients are reduced approximately 50 percent. Experiments were also performed with fully aerated water droplets falling freely through a nitrogen atmosphere. For this case, droplet surface area ranged from 0.15 to 0.50 cm^2. Transfer coefficients are found to increase with increasing droplet size. Although no direct comparison of droplet sizes could be made, it is concluded that the rate of oxygen transfer for both inward and outward transfer from a droplet is not substantially different

BASIC STUDIES
experimental
reaeration

C-6	Chasick, A H Bootes, R L DETERMINING THE EFFICIENCY OF AIR FILTERS Water Works and Wastes Eng v 1 n 1 1965 p 50	EQUIPMENT waste treatment diffusers
C-7	Chernykh, E M O NEUSTOICHIVOSTI SFERICHESKOGO GAZOVOGO PUZYRAYA V POLE PEREMENNOGO DAVLENIYA Akademiya Nauk Izvestiya Mekhanika Zhidkosti i Gaza n 1 Jan-Feb 1967 p 38-42 Instability of spherical gas bubble in variable pressure field; stability of radial motion of bubble boundary in incompressible nonviscous liquid is investigated for case of variable external pressure; possibility of steady motion existence is investigated for case of monotonic and periodic time functions of external pressure; it is proved that stability is only possible for infinitely large radii of bubble, or under very particular assumptions regarding initial conditions and pressure variations. In Russian (EI 1967)	BASIC STUDIES bubbles theoretical
C-8	Churchill, M A EFFECT OF DENSITY CURRENTS UPON RAW WATER QUALITY J American Water Works Assoc v 39 n 4 1947 p 357-360	BASIC STUDIES reservoirs experimental reaeration oxidation
C-9	Churchill, M A Buckingham, R A STATISTICAL METHOD FOR ANALYSIS OF STREAM PURIFICATION CAPACITY Sewage and Ind Wastes v 28 Apr 1956	BASIC STUDIES streams experimental reaeration
C-10	Churchill, M A EFFECTS OF STORAGE IMPOUNDMENTS ON WATER QUALITY Proc ASCE v 83 n SA 1 Feb 1957 Discusses thermal stratification and effects on dissolved oxygen	BASIC STUDIES reservoirs experimental reaeration oxidation
C-11	Churchill, M A EFFECT OF WATER TEMPERATURE ON STREAM REAERATION Proc ASCE v 87 n SA 6 1961 p 59	BASIC STUDIES streams experimental reaeration
C-12	Churchill, M A Buckingham, R A Elmore, H L PREDICTION OF STREAM REAERATION RATES Proc ASCE v 88 n SA 4 Jul 1962 p 1-46 Results are given of many field measurements of actual rates at which river water that is low in dissolved oxygen, but free of organic pollution, absorbs oxygen from atmosphere; by using dimensional analysis and multiple-regression techniques, observed reaeration rates have been related to hydraulic properties of river channels; several reaeration formulas thus developed can be used to predict accurately rate at which oxygen will be absorbed by water flowing in natural stream channels	BASIC STUDIES streams experimental reaeration

C-13 Churchill, M A Nicholas, W R
EFFECTS OF IMPOUNDMENTS ON WATER QUALITY
National Symposium on Quality Standards for Natural Waters Ann Arbor Mich Paper 2P1-1 Jul 1966

Results of selected studies of the quality of water flowing through large main river reservoirs in the Tennessee Valley are discussed. Selected data on the quality of water found in certain upstream storage reservoirs–primarily Guntersville, Wheeler, and Pickwick–are also presented. A beginning is made on the difficult job of predicting concentrations of DO in water released through low-level outlets from large storage impoundments. These first attempts are discussed and given an indication of the direction in which current studies are progressing. A preliminary DO prediction equation is given. As more data become available, the equation will be expanded to consider several pertinent water quality factors (biochemical oxygen demand, chemical oxygen demand, and nutrients) in the reservoir inflow, thus permitting more accurate predictions to be made for reservoir project design, operation, and water quality conditions

BASIC STUDIES
reservoirs
experimental
reaeration
oxidation

C-14 Churchill, M A Nicholas, W R
EFFECTS OF IMPOUNDMENTS ON WATER QUALITY
Proc ASCE v 93 n SA 6 Dec 1967 p 73-90

Changes occurring in the quality of water during its passage through Tennessee River reservoirs and during lengthy storage in tributary impoundments are observed. Seasonal variations of temperatures of water discharged from main-river impoundments are discussed. DO concentrations in the water discharged from main- river reservoirs recede during the summer months but do not reach the low concentrations observed below storage impoundments. Both total coliform and fecal coliform concentrations in main stream reservoirs increase greatly below local municipalities. In tributary storage impoundments strong thermoclines develop in early spring, and relatively cool water, low in DO, is discharged through low- level power intakes well into or throughout the summer. Low DO concentrations are also caused by biological activity in eutrophic impoundments, inflow to which are otherwise relatively free of pollution. A multiple regression technique is used to develop an equation for predicting DO concentrations to be expected in releases from a proposed impoundment

BASIC STUDIES
reservoirs
experimental
reaeration
oxidation

C-15 Clair, William F Beck, John D
PITTSBURG GIVES ITS WATER THE AIR
Water and Waste Eng Jun 1969

Describes the Air-Aqua Turnover System installed on Pittsburg water supply reservoirs and results of aeration

EQUIPMENT
reservoirs
diffusers

C-16 Cleary, E J
THE REAERATION OF RIVERS
Ind Water Eng Jun 1966 p 16-21

EQUIPMENT
streams

C-17 Cleasby, J L Baumann, E R
OXYGENATION EFFICIENCY OF BLADED ROTOR
Water Pollution Control Federation J v 40 n 3 pt 1 Mar 1968 p 412-424

Oxygen transfer data for bladed-rotor mechanical aerator are presented and factors affecting oxygen transfer are discussed; test apparatus is examined; method used for efficiency determination is demonstrated by examples; included are results of 45 experimental runs plus comparison of diffused air

EQUIPMENT
mechanical
aerators

and mechanical aeration, showing rotor studied to be more efficient than hypothetical diffuser. 18 refs (EI 1968)

C-18 Cole, R
MOTION OF VAPOR BUBBLES IN SATURATED LIQUIDS
A I Ch E J v 13 n 2 Mar 1967 p 403-404
Data for vapor bubbles rising through saturated liquids have been obtained experimentally for variety of liquids under pressures ranging from 48 to 540 mm Hg; equivalent diameters of these bubbles ranged from 0.1 to 1.3 cm and thus cover precisely region in which H. D. Mendelson's analysis should be applicable; although considerable scatter of data is evident, it is apparent that mean of data is in agreement with Mendelson's analysis. 4 refs (EI 1967)

BASIC STUDIES
bubbles
experimental

C-19 Collins, R
SIMPLE MODEL OF PLANE GAS BUBBLE IN FINITE LIQUID
J Fluid Mechanics v 22 pt 4 Aug 1965 p 761-763
Study of large gas bubbles rising in liquids has been stimulated by analogy that bubble rising in bed of solid particles fluidized by vertical flow of gas through it, appears to behave like gas bubble rising in liquid; using method due to Davies and Taylor, simple model is employed to derive velocity of two-dimensional gas bubble rising in liquid along axis of channel of finite width (EI 1966)

BASIC STUDIES
bubbles
theoretical

C-20 Committee on Sanitary Engineering Research
SOLUBILITY OF ATMOSPHERIC OXYGEN IN WATER
Proc ASCE v 86 n SA 4 Jul 1960
For many years the saturation concentrations of gaseous oxygen dissolved in distilled water (as determined by Fox and reported by Whipple and Whipple) have been accepted as correct. Recently a group of researchers in England conducted experiments that showed significant differences from the previously accepted saturation concentrations. The research reported herein was conducted not to determine whether the new or the old values were correct but, independently, to determine true saturation values throughout the normal range of natural stream water temperatures

BASIC STUDIES
experimental
reaeration

C-21 Committee on Sanitary Engineering Research
EFFECT OF WATER TEMPERATURE ON STREAM REAERATION
Proc ASCE v 87 n SA 6 Nov 1961 p 59
A search of the literature indicated that the effect of water temperature on stream reaeration rates had not been definitely established. Extensive studies of actual stream reaeration rates required knowledge of this effect. Consequently, it was necessary to undertake experimental evaluation of the temperature coefficient, (θ), of the reaeration coefficient, (k_2). This was done in a series of carefully controlled, high-precision, laboratory experiments that indicate the reaeration rate increases geometrically at the rate of 2.41 percent per $^{\circ}$C

BASIC STUDIES
streams
experimental

C-22 Committee on
WATER QUALITY CRITERIA
Federal Water Pollution Control Admin Apr 1968 p 44
Includes recommendations for dissolved oxygen levels considered essential for maintaining native populations of fish and other aquatic life

GENERAL
criteria

C-23 Conway, R A Kumke, G W
FIELD TECHNIQUES FOR EVALUATING AERATORS
Proc ASCE v 92 n SA 2 Apr 1966 p 21-42

Rational design and operation of an aerated biological unit requires a knowledge of the oxygen-transfer capacity of the aeration systems either under consideration or installed. Detailed methods are described for use by operating engineers in injecting the required performance data through tests of commercial aerators installed in full-scale basins. The essential features of oxygen-transfer theory are reviewed together with the relationships needed to adjust the test data to specified conditions. Two important test conditions, the required auxiliary measurements, and the basic oxygen-transfer measurements are enumerated. The results of full-scale tests based on oxygenation rates, gas-stream oxygen balances, sulfite-ion depletion rates, and biological oxygen-uptake rates are presented for large sparged turbine and entrainment aerators. The ASCE Committee on Sanitary Engineering Research is considering means of collecting, correlating, and publishing the results obtained by plant engineers and their consultants in using these techniques to conduct aerator tests

EQUIPMENT
waste treatment
mechanical
aerators

C-24 Coon, C P C Campbell, H
DIFFUSED AERATION IN POLLUTED WATER
Water and Sewage Works v 114 1967 p 461

EQUIPMENT
waste treatment
diffusers

C-25 Coulter, J B
OBJECTIVES AND CRITERIA FOR WATER POLLUTION CONTROL
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 261-278

Discusses the judgment involved in establishing water quality criteria and the economic analysis of benefits in potential water uses

GENERAL
criteria
economics

C-26 Courchaine, R J
SIGNIFICANCE OF NITRIFICATION IN STREAM BALANCE—EFFECTS ON THE OXYGEN BALANCE
J Water Pollution Control Federation v 40 n 5 May 1968 p 835

BASIC STUDIES
streams
experimental
oxidation

C-27 Curtet, R Djonin, K
ETUDE D'UN ECOULEMENT MIXTE AIR-EAU VERTICAL DESCENDANT—REGIMES, EVOLUTION DE LA CONCENTRATION
Houille Blanche v 22 n 5 1967 p 531-550

Study of flow and concentration conditions of vertical downward mixed water and air flow; emulsion formed by jet of water on impact against free water surface in vertical cylindrical duct is discussed and flow conditions are classified in terms of initial data for flow without air, stable air entrainment, and air entrainment with unstable pockets; air concentration pattern in water is measured by gamma-ray technique; mean slip velocity theory is discussed. In French (EI 1968)

BASIC STUDIES
experimental
reaeration

D

D-1 Dal'Man, V V Zhilyaeva
INVESTIGATION OF LONGITUDINAL MIXING DURING BUBBLING IN STRAIGHT-THROUGH FLOW-TYPE REACTOR COLUMNS
Chem and Tech of Fuels and Oils (English translation of Khimiya i Teknologiya Topliv i Masel) p 12 Dec 1965 p 941-945
Study was made in steel and glass columns up to 9 m high and 4.1 to 29.6 cm ID; bubblers at bottom consist of porous cermet and stainless steel plates; values of turbulent diffusion coefficient D under steady state and transient conditions were obtained using pulse and concentration shift methods; experimental plots are drawn correlating Peclet diffusion number, true mean liquid velocity, coefficient f and D with gas velocity; results agree with calculated values. 20 refs (EI 1967)

BASIC STUDIES
bubbles
experimental

D-2 Danckwerts, P V
SIGNIFICANCE OF LIQUID FILM COEFFICIENT IN GAS ABSORPTION
Ind and Eng Chem v 43 n 6 Jun 1951 p 1460
Describes extension of penetration theory with emphasis on concept of surface renewal

BASIC STUDIES
theoretical
reaeration

D-3 Davenport, W G Richardson, F D
SPHERICAL CAP BUBBLES IN LOW DENSITY LIQUIDS
Chem Eng Sci v 22 n 9 Sep 1967 p 1221-1235
Measurements have been made of rising velocities and shapes of spherical cap bubbles in column 15 cm in diameter; liquids used were water, aqueous solutions of polyvinyl alcohol (PVA) with viscosities up to 216 centipoise and ethyl alcohol; gases were air, nitrogen, and carbon dioxide; with carbon dioxide, mass transfer coefficients were also obtained; relationships between measured quantities and properties of various liquids are considered; liquid viscosities up to 50 centipoise have no effect on either rising velocity or shape of spherical cap bubbles. 20 refs (EI 1968)

BASIC STUDIES
bubbles.
experimental

D-4 Davis, R E Acrivos, A
INFLUENCE OF SURFACTANTS ON CREEPING MOTION OF BUBBLES
Chem Eng Sci v 21 n 8 Aug 1966 p 681-685
Simple model is proposed for creeping motion of bubble contaminated with "insoluble" surface-active agent; existence of stagnant cap over rear of bubble is taken for granted and cap size and associated bubble drag are then computed theoretically, as functions of surface pressure at which contaminant film collapses; model, which employs no adjustable parameters, is consistent with experimental observations and, in particular, explains success of empirical correlation relating bubble drag to Bond number (EI 1967)

BASIC STUDIES
bubbles
experimental

D-5 De Nevers, N
BUBBLE DRIVEN FLUID CIRCULATIONS
A I Ch E J v 14 n 2 Mar 1968 p 222-226
Bubble-driven fluid circulations are present in bubble columns, gas lifts, pool boiling, etc; their mechanism is shown to be quite similar to mechanism of natural convection but with much larger driving forces; these circulations are stable in many baffled systems but unstable and rapidly changing in size,

BASIC STUDIES
bubbles
experimental

shape, and orientation in unbaffled systems; effect of these circulations in bubble columns is to lower holdup and vapor residence time, thus decreasing mass-transfer efficiency of column. 14 refs (EI 1968)

D-6 Derby, Ray L
CHLORINATION OF DEEP RESERVOIRS FOR TASTE AND ODOR CONTROL
J American Water Works Assoc v 48 Jul 1956 p 777
Reports attempts to mix two Los Angeles reservoirs by compressed air introduced through a perforated hose; water was lifted in large quantites but fell back to the bottom because of inadequate horizontal circulation

EQUIPMENT
diffusers
reservoirs

D-7 Diachishin, A N
discussion of MECHANISM OF REAERATION IN NATURAL STREAMS by O'Connor and Dobbins
Trans ASCE v 123 1958 p 672

BASIC STUDIES
streams
experimental
reaeration

D-8 Dietrich, K R
DAS DIFFUMAT-BELUEFTUNGSSYSTEM
Gesundheits-Ingenteur v 87 n 9 Sep 1966 p 257-261
"Diffumat" aeration system; illustrated description of new patented system in which aeration of activated sludge is carried out by injecting compressed air in form of large bubbles at bottom of high (8 m and more) slim tanks; advantages of this system over surface absorption systems with water stirring and other air injection systems are shown in table listing oxygen transfer and electric energy consumption. In German (EI 1967)

EQUIPMENT
waste treatment
diffusers

D-9 Dijkman, H K M Vrengdenhil, C B
THE EFFECT OF DISSOLVED GAS ON CAVITATION IN HORIZONTAL PIPELINES
J of Hydraulic Res v 7 n 3 1969
In a horizontal pipeline a pump failure may cause water-column separation at intermediate points of the pipeline. In this paper a mathematical description is given for the case of water containing dissolved gas. The main assumption is that the gas collects into a single cavity at the top of the pipeline. Using this model, the effect of the gas is considered by comparison with previous results for pure water. As a provisional conclusion it is found that the pressure-rise after compression of the cavity is less serious than in the case with vapor only

CAVITATION

D-10 DiToro, D M O'Connor, D J
THE DISTRIBUTION OF DISSOLVED OXYGEN IN A STREAM WITH TIME VARYING VELOCITY
Water Resources Res v 4 n 3 1968 p 639

BASIC STUDIES
streams
experimental
reaeration

D-11 Dobbins, William E
BOD AND OXYGEN RELATIONSHIPS IN STREAMS
Proc ASCE v 90 n SA 3 Jun 1964 p 53-79; closure in v 91 n SA 5 Oct 1965 p 549-555

BASIC STUDIES
streams
experimental
reaeration
oxidation

D-12 Dobbins, W E
DIFFUSION AND MIXING
Boston Soc Engrs J v 52 n 2 Apr 1965 p 108-128
Based on Fick's laws of diffusion, and convection, and movement of nonconservative substances analysis is made on transport of sediment in river, and river and estuary pollution; diagrams are plotted for variation of eddy diffusivity with scale, rate of absorption of oxygen at fixed point on surface, and oxygen absorption coefficients. 20 refs (EI 1966)

BASIC STUDIES
streams
estuaries
experimental
reaeration

D-13 Dobbins, W E
MECHANISM OF GAS ABSORPTION BY TURBULENT LIQUIDS
Advances in Water Res Proc 1st International Conf Water Pollution Res Pergamon Press Ltd London England v 2 1964 p 61
Develops a theoretical model for reaeration in turbulent systems. Best fit to experimental results occurs with model consisting of continuously replaced laminar liquid film. Includes good review and evaluation of previous theories. Discussions of paper are good

BASIC STUDIES
streams
theoretical
experimental
reaeration

D-14 Dobbins, William E
THE NATURE OF THE OXYGEN TRANSFER COEFFICIENT IN AERATION SYSTEMS
Part 2-1 of Biological Treatment of Sewage and Ind Wastes by McCabe and Eckenfelder Reinhold New York N Y 1956

EQUIPMENT
waste treatment

D-15 Downing, A L Bayley, R W Boon, A G
THE PERFORMANCE OF MECHANICAL AERATORS
Inst Sewage Purification J Proc pt 3 1960 p 231-247
The paper compares oxygenation efficiencies for several types of surface aerators of British manufacture. Effects of temperature, immersion depth, surfactants, and foam suppressors are discussed. The performance of one type is compared with aeration at weirs. A short discussion of diffusers is included

EQUIPMENT
mechanical aerators
cascades
diffusers

D-16 Downing, A L Melbourne, K V Bruce, A M
THE EFFECT OF CONTAMINANTS ON THE RATE OF AERATION OF WATER
J of Applied Chem v 7 1957 p 590

BASIC STUDIES
experimental
reaeration

D-17 Downing, A L Truesdale, G A
SOME FACTORS AFFECTING THE RATE OF SOLUTION OF OXYGEN IN WATER
J of Applied Chem v 5 Oct 1955 p 570
The effects of a number of factors on the rate of solution of oxygen in fresh and saline water were investigated experimentally to provide information about reaeration in a polluted estuary

BASIC STUDIES
experimental
reaeration

D-18 Drachev, S M
PROTSESSY SAMOOCHISHCHENIYA V SILNO SAGRYAZNENNYKH REKAKH S MALYM TASKHODOM
(Processes of Self-Purification in Very Polluted Rivers with a Small Flow)
Vodosnabzh i santekhnika v 15 n 7 1940 In Russian

BASIC STUDIES
streams
reaeration

D-19 Dresnack, R Dobbins, W E
NUMERICAL ANALYSIS OF BOD AND DO PROFILES
Proc ASCE v 94 n SA 5 Oct 1968 p 789-807

The variation of Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) along a stretch of a polluted natural stream can be represented by two second-order partial differential equations. These equations are similar to the equation representing the conduction of heat in solids, with the exception that the stream equations contain additional lower-order terms. Analytical solutions have been obtained for many cases of the heat-conduction problem. However, the presence of the lower-order terms and the complexities of many of the boundary conditions make it impossible to obtain analytical solutions to the BOD and DO profile equations for most cases of practical interest. Furthermore, the numerical procedures which have been found to work for the solution of the heat conduction equation are not satisfactory for the BOD and DO equations because of the effects introduced by the lower-order terms. Procedures are presented for the numerical solution of the BOD and DO equations under temporally and spatially varying BOD and DO inputs. The procedures described are confined to the condition of steady, uniform stream flow

BASIC STUDIES
streams
theoretical
reaeration
oxidation

D-20 Driver, E E Krenkel, P A
THE EFFECTS OF MODIFICATIONS OF THE FLOW REGIME ON WASTE ASSIMILATIVE CAPACITY OF THE COOSA RIVER
Vanderbilt U Dept of Civil Eng Sanitary and Water Res Eng Tech Report No. 5 1965 Nashville Tenn

Discusses the assimilative capacity and hydraulic characteristics of the Coosa River, Georgia, and the effects of waste discharges from the Georgia Kraft Company, Weiss Dam, and operations of Allatoona Dam on water quality. A reduction of 80 percent of the waste assimilative capacity may be directly attributed to the impoundment of Coosa River by Weiss Dam and the stratification induced by the heated discharge contributed by a steam electric generating plant

BASIC STUDIES
streams
experimental
reservoirs
reaeration

D-21 Dziallas, R Voith, J M
FRANCIS TURBINES UNDER PARTIAL LOAD AND OVERLOAD
Transl from German by W O Wunderlich and S Vigander Tennessee Valley Authority Nov 1966

Includes discussion of aeration for control of draft tube disturbances. Suggests that, at atmospheric pressure, an airflow corresponding to approximately 0.25 to 1 percent of the full load turbine discharge is necessary for control of the disturbances. States that larger quantities of air, under certain circumstances, may cause more serious distrubances, and in any case lead to a drop in efficiency

EQUIPMENT
streams
turbine
injection

E

E-1 Eckenfelder, W W Jr
ABSORPTION OF OXYGEN FROM AIR BUBBLES IN WATER
Proc ASCE v 85 n SA 4 Jul 1959
Several correlations have been developed to define the absorption of oxygen from gas bubbles in water. In most cases, these correlations have been derived from bubble cap plates and other low head devices. This paper develops relationships between the liquid film coefficient, K_L and the Reynolds and Schmidt Numbers at liquid submergence depth up to 15 feet. Correlations are also developed relating the overall coefficient, K_La, to pertinent process variables. The correlations developed from laboratory data are extended to commercial diffusion devices

BASIC STUDIES
bubbles
experimental

E-2 Eckenfelder, W W Jr
OXYGEN TRANSFER AND AERATION
Manual of Treatment Processes v 1 Environmental Sci Services Corp 1968
Discusses effect of waste characteristics on oxygen transfer, aerator types, and aeration design for application to sewage treatment problems

EQUIPMENT
waste treatment

E-3 Eckholdt, M
THE ARTIFICIAL AERATION OF RIVER WATER ACCORDING TO R. VON WOLFF
Soutsche Gewasserkundlicke Mitteilungen v 10 n 1 1966 p 1-11
Results of experiments at the Saar Hydroelectric Station at Mettlack (1964) In German

EQUIPMENT
streams
turbine injection

E-4 Edwards, R W Owens, M
THE OXYGEN BALANCE OF STREAMS
Ecology and the Industrial Society Oxford 1965

BASIC STUDIES
streams
experimental
reaeration

E-5 Edwards, R
PLANTS AS OXYGENATORS IN RIVERS
Water Res v 2 1968 p 243

BASIC STUDIES
streams
experimental
photosynthesis

E-6 Einstein, A
INVESTIGATIONS ON THE THEORY OF THE BROWNIAN MOVEMENT
Ann Physik v 17 1905 p 549

BASIC STUDIES
experimental

E-7 Elder, R A Smith, M N Wunderlich, W O
AERATION EFFICIENCY OF HOWELL-BUNGER VALVES
J Water Pollution Control Federation v 41 n 4 Apr 1969 p 629-639
The effectiveness of the Howell—Bunger valve as a device for aerating discharges from reservoirs was investigated under conditions of free discharge to a catchment area and discharge to a tailwater pool. The results showed that the aeration efficiency is related to the discharge velocity, and that thickness of jet and initial dissolved-oxygen concentration have little effect. At discharge velocities of 30 ft per sec or more the valve proved a highly efficient aeration device for both types of discharge, while at lower velocities it was slightly more effective for free discharges than for confined discharges. A further series of tests is planned to investigate the aeration achieved when the valve discharges into a tunnel (WPA 1502 Aug 1969)

EQUIPMENT
streams
Howell-Bunger valves

E-8 Elmore, H L
EFFECT OF WATER TEMPERATURE ON STREAM REAERATION
Proc ASCE n SA 6 1961 p 59

BASIC STUDIES
streams
experimental
reaeration

E-9 Erickson, L E Ho, Y S Fan, L T
MODELING AND OPTIMIZATION OF STEP AERATION WASTE TREATMENT SYSTEMS
Water Pollution Control Federation J v 40 1968 p 717

Several flow systems for use with step aeration process were examined under optimal operating conditions—completely mixed tanks-in-series systems, plug-flow systems, and composite of two; allocation of feed along system is desirable and method of determining optimum allocation and tank volumes for given type of step aeration is shown; mathematical model developed is based on certain simplifying assumptions and is considered only approximation of complex treatment process

EQUIPMENT
waste treatment

E-10 Ettelt, G A
ACTIVATED SLUDGE THICKENING BY DISSOLVED AIR FLOTATION
Purdue U—Eng Extension Ser 117 pt 1 1965 p 210-244

Use of dissolved air flotation process for sludge thickening at Chicago Southwest plant is described; theoretical aspects of flotation are expressed in mathematical relationships; laboratory tests on activated sludge were conducted in pressure cell; subsequent tests were performed to experimentally correlate terminal velocity of activated solids for various conditions; two proprietary dissolved air flotation pilot units of approximately 150 gpm feed rate were tested; performance of flotation unit was dependent on proper inlet design to maximize adhesion efficiency. Before 19th Industrial Waste Conference May 1964 (EI 1965)

EQUIPMENT
waste treatment
misc uses

F

F-1 Fair, G M Geyer, J C — GENERAL
WATER SUPPLY AND WASTE WATER DISPOSAL
John Wiley and Sons Inc New York N Y 1954

F-2 Falk, A — EQUIPMENT; waste treatment
EINSATZ VON KOLBENKOMPRESSOREN AUF KLAERANLAGEN
Gas- u Wasserfach v 106 n 32 Aug 1965 p 903-905
Use of piston compressors in sewage treatment plants; certain aeration processes can be aided by compressed air, such as large delivery blowers with low pressure for aerobic decomposition, for delivery of sludge and its by-products where fast rotary pumps were found insufficient; compressed air has been found economical in transportation of sludge between treatment and drying plants separated by great distances and at different levels; procedure and equipment, and integration for automatic control (EI 1966)

F-3 Fish, F F Hull, C H J Peters, B J Knight, W E — BASIC STUDIES; reservoirs; experimental
A STUDY OF THE EFFECTS OF A SUBMERGED WEIR IN THE ROANOKE RAPIDS RESERVOIR UPON DOWNSTREAM WATER QUALITY
Special Report No. 1 Roanoke River Studies
Compiled by Special Report Committee for Committee for Roanoke River Studies Feb 6 1958

F-4 Fischer, H B — BASIC STUDIES; streams; theoretical; experimental
DISPERSION PREDICTIONS IN NATURAL STREAMS
Proc ASCE v 94 n SA 5 1968 p 927

F-5 Fischerstrom, N C H — EQUIPMENT; waste treatment; diffusers
LOW PRESSURE AERATION OF WATER AND SEWAGE
Proc ASCE v 86 n SA 5 Sep 1960
Based on simplified theoretical considerations, a calculable system utilizing dispersed air at shallow depths has been developed. Elaborate tests and full-scale operation have proved that it is possible to obtain a good economy and an extremely high oxygenation capacity with this principle and perforated pipes as air distributors. Clogging of the pipes has been studied and satisfactorily eliminated

F-6 Ford, Maurice E Jr — EQUIPMENT; reservoirs; diffusers
AIR INJECTION FOR CONTROL OF RESERVOIR LIMNOLOGY
J American Water Works Assoc v 55 Mar 1963 p 267
Describes trials at Lake Wohlford, Calif. using compressed air to mix stratified water; lake was completely destratified after 58 hours of operation

F-7 Ford, M E Jr — EQUIPMENT; reservoirs; diffusers
ARTIFICIAL CONTROL OF RESERVOIR LIMNOLOGY AND ITS EFFECTS ON WATER QUALITY
Paper presented at the Calif Section Fall Conf Santa Monica Calif Oct 25 1962

F-8 Fortescue, G E Pearson, J R A — BASIC STUDIES; reaeration
ON GAS ABSORPTION INTO A TURBULENT LIQUID
Chem and Eng Sci v 22 1967 p 1163

F-9 Foster, J M Botts, J A Barbin, A R Vachon, R I
BUBBLE TRAJECTORIES AND EQUILIBRIUM LEVELS IN VIBRATED LIQUID COLUMNS
ASME–Paper 68-FE-1 for meeting May 6-9 1968

Analysis of bubble behavior in vertically vibrated liquid column and experimental results of equilibrium level determinations are presented; analysis avoids usual approximation of small bubble pulsation and predicts nonharmonic volume pulsation; it can be used to predict bubble trajectories and equilibrium levels; vibrational amplitude affects bubble motion indirectly through its effect on thermodynamic behavior of bubble; experimental results compare favorably with analysis (EI 1968)

BASIC STUDIES
bubbles
theoretical
experimental

G

G-1 Gal-Or, B Resnick, W
MASS TRANSFER FROM GAS BUBBLES IN AGITATED VESSEL WITH AND WITHOUT SIMULTANEOUS CHEMICAL REACTION
Chem Eng Sci v 19 n 9 Sep 1964 p 653-663
Model permits prediction of total mass transfer rates for sparingly soluble gas in gas-liquid contactor; model is based on average residence time of gas bubbles in continuous phase, and permits estimation of rate of diffusion per unit area as well as total area for diffusion; equations have been solved for range of variables and results are presented graphically (EI 1965)

BASIC STUDIES
bubbles
theorectical

G-2 Gameson, A L H Truesdale, G A Downing, A L
RE-AERATION STUDIES IN A LAKELAND BECK
J Inst Water Engr (Brit) v 9 1955 p 571
Develops a theoretical model for estimating reaeration in turbulent streams

BASIC STUDIES
streams
theoretical
experimental
reaeration

G-3 Gameson, A and others
SOLUBILITY DATA FOR SALT WATER
J of Applied Chem v 5 1955 p 502

BASIC STUDIES
experimental
reaeration

G-4 Gameson, A L H Truesdale, G A
SOME OXYGEN STUDIES IN STREAMS
J Inst of Water Eng Nov 1955

BASIC STUDIES
streams
experimental
reaeration

G-5 Gameson, A Truesdale, G A Varley
SOME FACTORS AFFECTING THE AERATION OF FLOWING WATER
Water and Sanitary Eng v 6 n 2 Jul 1956 p 52

BASIC STUDIES
streams
experimental
reaeration

G-6 Gameson, A
WEIRS AND THE AERATION OF RIVERS
J Inst of Water Engrs v 11 n 6 Oct 1957 p 477
Measurements at a number of weirs resulted in the relationship:

$$r = 1 + abh/_2$$

Where r is the ratio of upstream deficit to downstream deficit,

a = 1.25 in slightly polluted water, 1.0 in moderately polluted water, and 0.85 in sewage effluents;
b = 1 for a free weir, 1.3 for a step weir, h is the height of fall in meters

EQUIPMENT
streams
cascades

G-7 Gameson, A L H Vandyke, K G Ogden, C G
THE EFFECT OF TEMPERATURE ON AERATION AT WEIRS
Water and Water Eng (Brit) v 62 1958 p 489

EQUIPMENT
streams
cascades

G-8 Gannon, J J
RIVER AND LABORATORY BOD RATE CONSIDERATIONS
Proc ASCE v 92 n SA 1 Feb 1966 p 135-161
Differences observed between laboratory bottle BOD rate, and river BOD rate, motivated investigation of river BOD conditions to develop better understanding of deoxygenation component of river oxygen balance

BASIC STUDIES
streams
experimental
oxidation

relationship, limiting consideration, however, to effect of BOD rate; two river situations in Mich., one domestic waste problem on Clinton River below Pontiac, Mich. waste treatment plant, other industrial problem on Tittabawassee River below Dow Chemical Co. at Midland were studied. 39 refs (EI 1966)

G-9 Gannon, J J
AERATION AT WASTE TREATMENT PLANT OUTFALL STRUCTURES
Water and Wastes Eng v 4 n 4 Apr 1967 p 62-65
Significance of aeration at waste treatment plant outfall structures is discussed and illustrated in terms of two situations—Pontiac, Mich., waste treatment plant, discharging its effluent into Clinton River, and Dow Chemical Co. waste treatment plant at Midland, Mich., discharging its effluent into Tittabawassee River; comparisons made between observed and predicted results, using equations developed by British workers studying aeration at weir systems, indicate good agreement for Pontiac, but indicate that predictions are about 13 to 14 percent higher than observed results for Dow. 12 refs (EI 1967)

EQUIPMENT
streams
cascades

G-10 Garancher, J
LA PROTECTION D'UN PORT PETROLIER PAR UN RIDEAU DE BULLES
Houille Blanche v 22 n 4 1967 p 387-390
Bubble screen protection for oil harbors is provided by submerged network of pipes discharging compressed air through row of nozzles along their top, and generating vertical bubble screens which form impenetrable barrier for any oil accidentally discharged into harbor; results obtained at several French ports are described; method can be used to protect beaches and river water intakes from pollution by oil and sewage. In French (EI 1968)

EQUIPMENT
diffusers
misc uses

G-11 Geckler, J R Mackenthun, K M Ingram, W M
GLOSSARY OF COMMONLY USED BIOLOGICAL AND RELATED TERMS IN WATER AND WASTE WATER CONTROL
Public Health Service Cincinatti Jul 1963

GENERAL
terms

G-12 Giebler, G Koppe, P
METHODE SUR BESTIMMUNG DER WIRKUNG DES OZONS BEI DER AUFBEREITUNG VON WASSER
Gas- u Wasserfach v 106 n 8 Feb 1965 p 215-219
Method of determining effect of ozone during water treatment; method consists of treating water with gas mixture containing ozone; effect of ozone is measured by determining content of substances remaining in water after treatment; design and performance of experimental equipment and data on chemical action of ozone In German (EI 1965)

BASIC STUDIES
waste treatment
experimental

G-13 Glover, Robert E
DISPERSION OF DISSOLVED OR SUSPENDED MATERIALS IN FLOWING STREAMS
U S Geological Survey Prof Paper No 433-B Washington D C 1964

BASIC STUDIES
streams
experimental

G-14 Godfrey, Richard G Frederick, Bernard J
DISPERSION IN NATURAL STREAMS
Open-File Reports U S Geological Survey Washington D C 1963
BASIC STUDIES
streams
experimental

G-15 Gomella, C
DIFFUSION DE L'OZONE DANS L'EAU
Houille Blanche v 22 n 4 1967 p 439-449
Ozone diffusion in water; physical and chemical features of ozone are reviewed, also how 10 to 20 g/cu m of ozonized air is obtained industrially; oxidizing effect of ozone on chemical compounds in water is discussed; ozone distribution and decrease in its residual proportion in water by self-destruction are considered theoretically; application technique was tested on industrial scale. In French with English summary (EI 1968)
BASIC STUDIES
waste treatment
experimental

G-16 Grace, J R Harrison, D
INFLUENCE OF BUBBLE SHAPE ON RISING VELOCITIES OF LARGE BUBBLES
Chem Eng Sci v 22 n 10 Oct 1967 p 1337-1347
Equations are derived in two and three dimensions which relate rising velocity of large bubble in inviscid liquid to its size and to radius of curvature of its leading edge; elliptical-cap and ovary ellipsoidal bubbles rise faster than corresponding circular- and spherical-cap bubbles, and this has been confirmed experimentally using "two-dimensional" air bubbles in water; bubbles take up elliptical shapes if they enclose surface (e.g., rod) as they rise, and stability of bubbles under these conditions is considered; relevant to behavior of bubbles in fluidized beds. 11 refs (EI 1968)
BASIC STUDIES
bubbles
theoretical
experimental

G-17 Grindrod, J
BRITISH RESEARCH ON AERATION AT WEIRS
Water and Sewage Works v 109 1962 p 395
Contains brief descriptions of aeration at weirs and mentions aeration occurring at sewage works outfalls
EQUIPMENT
streams
cascades

G-18 Guillaume, F
EVALUATING AERATION DEVICES
Water Pollution Control Ontario v 107 n 1 1969 p 26
The author discusses the article on evaluation of aeration devices, by Black, S. A., (see Water Pollution Abstract v 42 n 978 1969), and queries the practicality of the extension of the test procedure which rates the aerator using tap water, for evaluating its adequacy for intended use and its suitability for a particular plant design. Modifications in the procedure are suggested (WPA 1621 Aug 1969)
EQUIPMENT
waste treatment

G-19 Gunnerson, C G Bailey, T E
OXYGEN RELATIONSHIP IN THE SACRAMENTO RIVER
Proc ASCE v 89 n SA Aug 1963 p 95
A 15-month pollution survey of the Sacramento River showed the effects of agricultural, municipal, and industrial discharges into the river. Unexpected results of the investigation included the observation of nighttime increases and other anomalies in dissolved oxygen concentrations which limit both classical and modern approaches to characterizing oxygen relationships. Variations in respiration, which cannot be predicted with present knowledge, provide the best explanation of the observed anomalies. Additional study of changes in respiration rates of aquatic communities is required for predicting the response of a stream to waste discharges
BASIC STUDIES
streams
experimental
reaeration
oxidation
respiration

G-20 Gustafson, Bengt Wistberg, Nils
ACTIVATED SLUDGE PROCESS UNDER DEFINED CONDITIONS
Kungl Teknisha Hogsholan (Sweden) 1964

EQUIPMENT
waste treatment

G-21 Gutti, S R
BEHAVIOR OF SMALL GAS BUBBLES IN ACCELERATED LIQUID
Proc ASCE v 94 n HY 4 Jul 1968 p 1073-1082

Time dependent motion of small gas bubbles in liquids subjected to linear pressure gradient was studied; expression for bubble slip, was derived as function of liquid and gas densities, initial velocities, and liquid velocity gradient was studied; expression for bubble slip was derived as function of liquid and gas densities, initial velocities, and liquid velocities, and approaches value of 0.9967 for highly accelerating flows. 14 refs (EI 1968)

BASIC STUDIES
bubbles
experimental

H

H-1 Hamalainen, M
PREVENTING THE DEPLETION OF OXYGEN BY CHANGING THE HYPOLIMNION
Vesitalous v 10 n 3 1969 p 25-27
In winter the ice cover on many Finnish lakes causes oxygen depletion with adverse effects on water quality and fish. In the artificial lake Dammen, in Espoo, the problem has been solved by installing a siphon spillway composed of plastic pipes and extending into the hypolimnion so that a continuous circulation of water is maintained, giving a satisfactory concentration of oxygen throughout the year. The method is cheap and can be adapted for use in many lakes, including impounded lakes where the head of water can be utilized to produce the necessary circulation and prevent oxygen depletion in the hypolimnion. Water Pollution Abstracts

EQUIPMENT
reservoirs
misc equipment

H-2 Hanes, N B Irvine, R L
NEW TECHNIQUES FOR MEASURING OXYGEN UPTAKE RATES
J Water Pollution Control Federation v 40 n 2 Feb 1968 p 223

BASIC STUDIES
experimental
oxidation

H-3 Hann, R W Jr
WATER QUALITY ASPECTS OF WATER RESOURCES PLANNING
Texas A&M U Oct 1968
Textbook for course in water quality management for USBR personnel

GENERAL

H-4 Harleman, D R F Holley, E R
discussion of TURBULENT DIFFUSION AND THE REAERATION COEFFICIENT by Krenkel and Orlob
Trans ASCE v 128 III p 327-333 1963

BASIC STUDIES
streams
theoretical
experimental
reaeration

H-5 Harper, J F Moore, D W Pearson, J R A
EFFECT OF VARIATION OF SURFACE TENSION WITH TEMPERATURE ON MOTION OF BUBBLES AND DROPS
J Fluid Mechanics v 27 pt 2 Feb 1967 p 361-366
Boundary conditions at surface of small bubble rising in liquid are examined theoretically, and it is shown by order-of-magnitude arguments, which are confirmed by detailed calculation in special case, that although surface-tension gradients must always exist around bubble, they are too small to affect motion appreciably unless surface-active substances are present. 13 refs (EI 1967)

BASIC STUDIES
bubbles
theoretical

H-6 Hart, I C
NOMOGRAPHS TO CALCULATE DISSOLVED OXYGEN CONTENTS AND EXCHANGE (MASS TRANSFER) COEFFICIENTS
Water Res v 1 1967 p 391

BASIC STUDIES
experimental
reaeration

H-7 Hays, James R
MASS TRANSPORT MECHANISMS IN OPEN-CHANNEL FLOW
PhD Thesis Vanderbilt U Nashville Tenn 1966

BASIC STUDIES
streams
reaeration

H-8 Hazen, R
GETTING MORE FOR WATER POLLUTION CONTROL DOLLAR
Civil Eng (NY) v 37 n 12 Dec 1967 p 38-39
Present laws and policies that require waste water effluent treatment to be same regardless of effect on receiving water are unrealistic; reaeration of rivers can be done much more economically by reoxygenation than by dilution; cost might be $33/1,000 lb of oxygen added, compared to $250 for reservoir to supply extra water for dilution; zoning should allow waste producing industries only where adequate water is available; research money should be spent for usable information only, not to support laboratories and researchers;.halt should be called to producing volumes of statistics on needs and subsequent savings should be spent on construction (EI 1968)

GENERAL
economics

H-9 Hemphill, J
METHOD OF WINTERKILL PREVENTION
Arizona Game and Fish Dept 1954
Uses compressed air mixing of lakes to prevent ice forming and cutting off the oxygen supply

EQUIPMENT
reservoirs
diffusers
misc uses

H-10 Higbie, R
THE RATE OF ABSORPTION OF A PURE GAS INTO A STILL LIQUID DURING SHORT PERIODS OF EXPOSURE
Trans American Inst of Chem Eng v 21 1935 p 365
Compares experimental rates of gas absorption with rates predicted by Lewis-Whitman film theory and penetration theory. Primarily concerned with short exposure periods in industrial absorption applications

BASIC STUDIES
theoretical
experimental
reaeration

H-11 Hinde, J Nelson
REVITALIZING WATER THE NATURAL WAY
paper American Water Works Assoc 89th Annual Conf San Diego Calif May 18-22 1969
Describes the Air-Aqua system for controlled aeration of lakes and reservoirs. System releases air from a weighted valved tubing laid on the bottom of the lake; controlled bubble size produces a laminar uplift of a low-velocity nonturbulent flow which requires very little energy

EQUIPMENT
reservoirs
diffusers

H-12 Hinde Engineering Company
WATER IMPOUNDMENT RESERVOIR, HIGHLAND SEWER AND WATER AUTHORITY, HIGHLAND, PENNSYLVANIA
Sales brochure Air-Aqua Case History 2602 Hinde Eng Co Highland Park Ill
Describes the Air-Aqua aeration system installed at Lloydell Reservoir to improve water quality; cost amounts to $1.45 per day for electricity, maintenance and amortization for the 208-million-gallon reservoir

EQUIPMENT
reservoirs
diffusers

H-13 Holley, E R
UNIFIED VIEW OF DIFFUSION AND DISPERSION
Proc ASCE v 95 n HY 2 Mar 1969
Diffusion and dispersion are basically convective transport mechanisms. The method chosen for representing the convection in a mass balance equation is the determining factor in deciding whether diffusion or dispersion must be included in the conservation equation for a given flow. This principle is illustrated for molecular diffusion, turbulent diffusion, and longitudinal dispersion. In a given flow, the relative importance of diffusion or dispersion

GENERAL
terms

in different transport problems depends on the steepness of the concentration gradient. It is proposed that the term "diffusion" be reserved for transport that is associated primarily with time-averaged velocity fluctuations and that "dispersion" be used for transport associated primarily with the spatial average of velocity variations

H-14 Holley, E R
SOME DATA ON DIFFUSION AND TURBULENCE IN RELATION TO REAERATION
Research Report No 21 Water Resources Center Univ of Illinois July 1969

BASIC STUDIES
streams
experimental
reaeration

Heat was used as a tracer to determine diffusion rates immediately below the free surface both in the "film" region and in the remainder of the water in a mixing vessel. The results tend to indicate that model can be used to represent the downward transport of a substance which is being absorbed at the free surface. Apparently, the diffusion coefficient in the "film" can be either equal to or greater than the molecular coefficient depending on the amount of mixing at the free surface. Hot film anemometry was used to determine turbulence characteristics from 1 to 0.006 inch below the free surface of a laboratory open-channel flow. The energy spectra indicate no significant changes in the turbulence in this region. Thus, apparently turbulence exists right up to the free surface and in the "film" region. The amount of reliable data that was obtained was very limited.

H-15 Hooper, Frank F Ball, Robert C Tanner, Howard A
AN EXPERIMENT IN THE ARTIFICIAL CIRCULATION OF A SMALL MICHIGAN LAKE
Trans American Fisheries Soc v 82 1952 p 222

EQUIPMENT
reservoirs
pumps

Attempts to mix a stratified body of water using a gasoline-drive centrifugal pump on shore to withdraw water from the hypolimnion and discharging it on the surface of a barge

H-16 Huckabay, H K Keller, A G
AERATION ON AN INCLINED TRANSVERSELY CORRUGATED SOLID SURFACE
J Water Pollution Control Federation v 42 n 5 pt 2 May 1970

EQUIPMENT
streams
cascades

The "cascade board" aerates water by natural gravity flow down an inclined, transversely corrugated, solid surface. A study was carried out for angles of inclination of 5^o to 30^o from the horizontal. Flow rates of 0.02 to 0.08 mgd/ft of width (248 to 992 cu m/day/m of width), and temperatures of 83^o to 108^o F (28^o to 42^o C) were studied. Dissolved oxygen was measured by a microadaptation of the Winkler procedure. The mass transfer coefficient was correlated successfully in terms of flow rate and angle of inclination. The number of transfer units was found to be independent of flow rate and to correlate only with the angle of inclination. No optimum angle existed; however, the larger angles of inclination were more favorable to aeration

H-17 Hughmark, G A
HOLDUP AND MASS TRANSFER IN BUBBLE COLUMNS
Ind and Eng Chem—Process Design and Development v 6 n 2 Apr 1967 p 218-220

BASIC STUDIES
bubbles
experimental

Correlation for gas holdup in bubble columns predicts values with average absolute deviation of about 11 percent from experimental holdups; recent correlation for mass transfer from single gas bubbles in liquids is applicable to swarm data for bubble columns; illustrative problem is solved. 9 refs (EI 1967)

H-18 Hull, C H J
OXYGENATION OF BALTIMORE HARBOR BY PLANKTONIC ALGAE
J Water Pollution Control Federation v 35 May 1963 p 587-606

BASIC STUDIES
experimental
photosynthesis

H-19 Hull, C H J
PHOTOSYNTHESIS AS A FACTOR IN THE OXYGEN BALANCE OF RESERVOIRS
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 77-96
Describes studies on photosynthetic oxygenation in streams, estuaries and impoundments, and significance in controlling oxygen balance

BASIC STUDIES
reservoirs
experimental
photosynthesis

H-20 Hull, C H J
PHOTOSYNTHETIC OXYGENATION OF A POLLUTED ESTUARY
Advances in Water Pollution Res v 3
E. A. Pearson (ed), Proc International Conf on Water Pollution Res London, England Sep 3-7 1962 Pergamon Press London England 1964 p 347-374 disc on p 391-395
Abstract in: London Conf Abstracts
JWPCF v 34 Mar 1962 p 275-276

BASIC STUDIES
estuaries
experimental
photosynthesis

H-21 Humphrey, W H
REMOVAL OF AGGRESSIVE CARBON DIOXIDE FROM POTABLE WATERS
Water and Water Eng v 68 n 822 Aug 1964 p 324-327
Removal of CO_2 in excess of that required to maintain $CaCO_3/H_2CO_3$ equilibrium from water by aeration, marble, magnesite, lime, and dolomite filter methods; determination with aid of Tillmans graph, yielding aggressive CO_2 and probable pH values from free CO_2 and $CaCO_3$ concentrations; example of corrosiveness of agressive CO_2 on water systems (EI 1965)

BASIC STUDIES
experimental

H-22 Hunter, H M Potter, W J Lyons, E T
PROGRESS REPORT—AN INVESTIGATION OF THE EFFECT OF ENGINEERING STRUCTURES UPON THE DISSOLVED OXYGEN CONTENT OF STREAMS AND RESERVOIRS
USBR Denver Colo Report No CH-103 Apr 1961
Presents and discusses (1) analytical data obtained in preliminary investigations of (a) the dissolved oxygen content of streams and reservoirs on the Colorado—Big Thompson Project, and (b) chemical methods of determining the dissolved oxygen content of water samples; (2) recommendations for future investigative work in this field. Includes a bibliography with 348 references, many dealing with instrumentation and chemical analysis for determination of dissolved oxygen

BASIC STUDIES
streams
reservoirs
experimental
DO ANALYSIS
instrumentation

H-23 Hurwitz, E Nogaj, R U Roeber, J A
PERFORMANCE OF SURFACE AERATORS UNDER WIDELY VARYING LOADINGS IN ACTIVATED SLUDGE SYSTEM
Water and Sewage Works v 112 Nov 1965 p R-209-212 214-216 218
Dixon, Ill. sewage treatment plant was used to test performance of surface aerators under several process applications of activated sludge system; performance and operating data of plant and sludge processes; empirical formulas developed from studies are summarized; plant was operated as conventional activated sludge plant at conventional loadings; contact

EQUIPMENT
waste treatment
mechanical
aerators

stabilization plant at conventional loadings; contact stabilization plant at extended aeration loadings; and high rate activated sludge plant (EI 1966)

H-24	Hutchinson Sherwood LIQUID FILM IN GAS ABSORPTION Ind and Eng Chem Jun 1937 p 836	BASIC STUDIES *theoretical* experimental *reaeration*
H-25	Hutchison, G E A TREATISE ON LIMNOLOGY, VOL. I, GEOGRAPHY, PHYSICS AND CHEMISTRY John Wiley and Sons Inc New York N Y 1957 Discusses the formation and persistence of stratification in reservoirs	GENERAL

I

I-1 Iberall, A S Cardon, S Z
AERATION MASS TRANSFER RELATED TO REYNOLDS NUMBER
J Applied Chem v 16 n 2 Feb 1966 p 64-72
Study of aeration rate data for streams and laboratory channels shows that aeration rate can be correlated with Reynolds number and Schmidt number by suitable dimensionless mass-transfer parameter which varies only slowly over wide range of Reynolds number; this parameter, analog to similar correlations in heat- and mass-transfer fields, has two different near-constant levels, one in low Reynolds number regime corresponding to molecular diffusivity, and another in high Reynolds number regime corresponding to eddy diffusivity (EI 1966)

BASIC STUDIES
streams
experimental
reaeration

I-2 Ignjatovic, L R
EFFECTS OF PHOTOSYNTHESIS ON OXYGEN SATURATION
J Water Pollution Control Federation v 40 n 5 May 1968 p R151

BASIC STUDIES
experimental
photosynthesis

I-3 Imhoff Grabbe Albrecht
ERPROBUNG VERSCHIEDENER VERFAHREN ZUN KUNSTLICHEN GEWASSERBELUFTUNG (Testing of Various Methods to Artificially Aerate Water)
Vom Wasser 1968 Band XXXV In German

EQUIPMENT

I-4 Imhoff, K R
UEBER DIE REINIGUNGSLEISTUNG DER RUHRSTAUSEEN
Gas- u Wasserfach v 106 n 46 Nov 1965 p 1264-1267
On purification capacity of impounded reservoirs of Ruhr River; 100 treatment plants of region for purifying drinking water are successfully increased by four Ruhr reservoirs paying for themselves by hydroelectric power generation; 1960 to 1964 chemical-biological laboratory tests of reservoir waters are tabulated, and results show that free-flowing river self-purification recovery distance is shortened by 3.2 to 3.7 higher purification values/river km by flowing through reservoirs. 24 refs In German (EI 1966)

BASIC STUDIES
streams
reservoirs
experimental
reaeration

I-5 Imhoff, K R
OXYGEN MANAGEMENT AND ARTIFICIAL REAERATION IN THE AREA OF BALDENEY LAKE AND THE LOWER RUHR RIVER
Das Gas- und Wasserfach 109 Jahrg (1968) Heft 34 Seite 936-941 (Wasser-Abwasser) in German
The Ruhr River in Germany has presented a major pollution-control problem for a long time. Although only a small river, the equivalent of sewage from over 2 million population comes through the central area near the city of Essen. In addition to very strict control of effluents by waste treatment plants, the pollution control agency, the Ruhrverband, has applied instream aeration as a supplemental means. Three aeration methods have been used—by introducing air into hydraulic turbines, by diffusers (bubbling from submerged orifices), and by mechanical aerators. Technical analysis allows an economic comparison as follows. In order to remove organic pollution of one population equivalent, at times of low flow, the cost would amount to 0.81 DM for a mechanical aerator, and 0.22 DM with the turbine aerator, as compared to 4.0 DM for expansion of the treatment plant to achieve the same result. Other figures show the diffuser as much less economic than the

EQUIPMENT
streams
reservoirs
diffusers
mechanical aerators
turbine injection

mechanical aerator, though part of the extra cost is due to certain special circumstances. This result is in accord with recent American findings that instream aeration is an economical means in severe pollution situations. (Whipple-Rutgers)

I-6 Ingols, R S
POLLUTIONAL EFFECTS OF HYDRAULIC POWER GENERATION
Sewage and Ind Wastes v 29 1957 p 292-297
Discusses positive and negative effects of impoundments on downstream water quality, including reduction of DO

BASIC STUDIES
reservoirs
experimental

I-7 Ingols, R S
EFFECT OF IMPOUNDMENT ON DOWNSTREAM WATER QUALITY, CATAWBA RIVER, S. C.
J American Water Works Assoc v 51 n 1 Jan 1959 p 42-46
Reports on conditions causing oxygen depletion in the hypolimnion of a reservoir and oxygen depletion in the Holsten River

BASIC STUDIES
reservoirs
experimental
oxidation

I-8 Ingols, R S
SHORT TERM BOD
Water and Sewage Works v 115 1968 p 258

BASIC STUDIES
waste treatment
experimental
oxidation

I-9 Irwin, William H Symons, James M Robeck, Gordon G
IMPOUNDMENT DESTRATIFICATION BY MECHANICAL PUMPING
Federal Water Pollution Control Admin Cincinnati Mar 1966
Mechanical pumping was used to break up thermal stratification in four lakes in southern Ohio during the summer of 1964. The lake volumes were 98, 100, 120, and 1,260 acre-ft. Each impoundment was thermally and chemically stratified before pumping began. The equipment was a float-mounted, axial-flow pump, 13-acre-ft-per-day capacity, driven by a gasoline engine. The pump drew water from the bottom and discharged it at the surface. Profiles of temperature, pH, and concentrations of dissolved oxygen and carbon dioxide were taken before and after pumping. Data presented show that this method was effective in destratifying these lakes. In addition, the data show that water quality was improved by artificial destratification and that an entire impoundment could be mixed with the pump located at a single position. Some data are presented on total work requirements, but these were found to be dependent on the efficiency of the mechanical equipment and the percentage of cold water in the impoundment before pumping

EQUIPMENT
reservoirs
pumps

I-10 Isaacs, W P
ATMOSPHERIC OXYGENATION AND BIOLOGICAL DEOXYGENATION IN AN IDEALIZED STREAM FLOW MODEL
Dissertation Abstracts v 28 n 12 1968 p 5052
Chem Abstracts v 69 1968 p 7498

BASIC STUDIES
streams
theoretical
oxidation

I-11 Isaacs, W P Gaudy, A F Jr
ATMOSPHERIC OXYGENATION IN A SIMULATED STREAM
Proc ASCE v 94 n SA 2 Apr 1968 p 319-344
A simulated stream channel was used in laboratory investigations to determine a rational expression relating stream variables and fluid properties

BASIC STUDIES
streams
experimental
reaeration

which define the reaeration rate constant, K_2. Direct measurement of the reaeration coefficient at controlled depths and stream velocities enabled the development of a dimensionally homogeneous expression for K_2. The developed expression accounts for variations in K_2 due to changes in temperature as well as changes in fluid flow conditions. For the rectangular cross section employed in these studies, the reaeration rate constant, K_2, was found to be directly proportional to average stream velocity, and inversely proportional to the average stream depth raised to the 3/2 power. The constant of proportionality was found to be 3.053. When the same analytical approach was applied to the best available natural stream data, the proportionality constant obtained was 3.739. Both analyses yielded highly acceptable correlation coefficients. It is believed that the difference in the values of the proportionality constant is due primarily to differences in channel geometry, i.e., smooth rectangular laboratory channel versus irregular-shaped natural river channels

J

J-1 Jackson, D F
EFFECTS OF ALGAE ON WATER QUALITY
N Y State Dept Health—Water Quality Res Symposium 1st—Proc Feb 1964 p 2-23
Certain changes in water quality which are associated with dynamics of algae metabolism were studied; theoretical equation to evaluate phytoplankton dynamics is presented; factors of light and temperature are integrated to provide foundation for physiological process of photosynthesis; incident solar radiation, as well as compensation point of light, may be determined by means of submarine photometer; review of literature on investigations of effects and dynamics of algae. 53 refs (EI 1966)

BASIC STUDIES
theoretical
photosynthesis

J-2 Jackson, M L Collins, W D
SCALE-UP OF VENTURI AERATOR
Ind and Eng Chem—Process Design and Development v 3 n 4 Oct 1964 p 386-393
Energy losses and oxygen transfer characteristics of two sizes of Venturi devices, designed for air aspiration by liquid, were compared; in large-scale system, transfer factors for water and for very dilute sulfite solutions, corresponding to falling and constant driving force conditions, were essentially equal (EI 1965)

EQUIPMENT
Venturis

J-3 Jackson, R Bradney, L Bragstad, R E
SHORT-TERM AERATION SOLVES ACTIVATED SLUDGE EXPANSION PROBLEMS AT SIOUX FALLS
J Water Pollution Control Federation v 37 n 2 Feb 1965 p 255-261
Operation of sewage treatment plant for treatment of waste water at Sioux Falls, S. Dak., that is complicated by high-strength industrial meat waste and receiving stream which at times measures nearly zero flow; based on pilot plant studies, full-scale short-term aeration system was designed and installed; eight aerators were installed in each of three passes of existing aeration tank; impellers used are flat-blade turbines; aeration tanks were modified to provide for cross-flow feeding; plant was designed to operate activated sludge portion according to efficiency of trickling filters (EI 1965)

EQUIPMENT
waste treatment
mechanical aerators

J-4 Jameson, G J Kupferberg, A
PRESSURE BEHIND BUBBLE ACCELERATING FROM REST—SIMPLE THEORY AND APPLICATIONS
Chem Eng Sci v 22 n 7 Jul 1967 p 1053-1055
When gas bubble is formed at point in relatively inviscid liquid, its initial motion is determined by balance between buoyancy and inertia; bubble breaks off when its base reaches gas supply point and accelerates away from source; in its wake, bubble leaves distinct pressure field; it is suggested that this pressure, whose approximate magnitude can be calculated by potential flow theory, is responsible for phenomenon of dumping or weeping on sieve trays; it may also have important effects in other situations involving accelerating bubbles such as fluidized beds and in nucleate boiling. 7 refs (EI 1968)

BASIC STUDIES
bubbles
theoretical

J-5 Jawonski, Nonhert A Weber, Walter J Deininger, Roolf A
OPTIMAL RELEASE SEQUENCES FOR WATER QUALITY CONTROL IN MULTIPLE-RESERVOIR SYSTEMS
Michigan U (sets T-68-1) Apr 1968

GENERAL

J-6 Jayne, T D Sedlacek, R J
DEVELOPMENT AND CONSTRUCTION OF AN INSTRUMENT FOR MEASUREMENT OF STREAM AERATION RATE
Public Health Service Contract No. PH-86-64-14 Rand Development Corp Cleveland 1964

DO ANALYSIS
instrumentation

J-7 Jenks, J H
HIGH-RATE PONDING SYSTEM SOLVES SEASONAL HIGH LOAD PROBLEM FOR HAYWARD, CALIFORNIA
Water and Waste Eng v 3 n 11 Nov 1966 p 50-53

Feature of program of waste water treatment and disposal is use of high-rate recirculation and aeration ponding system; to meet initial treatment needs for 19 mgd of combined sanitary sewage and seasonal high-strength wastes associated with local food processing industry; single "Inka" grid installed in high-rate pond was operated at submergence of 28 in.; air was generally supplied to grid at rate of 500 cfm; at that rate, blower power requipment was 5 hp; full-scale ponds are divided into four separate units, each with its own recirculation and aeration system (EI 1967)

EQUIPMENT
waste treatment
diffusers

J-8 Johnson, A I Besik, F Hamielec, A E
MASS TRANSFER FROM A SINGLE RISING BUBBLE
Canadian J of Chem Eng v 47 n 6 Dec 1969 p 559

Describes water column experiments to determine bubble sizes and transfer rates of carbon dioxide, ethylene, and butene. Results are compared with previous investigations and an empirical equation is presented

BASIC STUDIES
bubbles
experimental

J-9 Johnson, V E Jr
CAVITATION IN HYDRAULIC STRUCTURES: MECHANICS OF CAVITATION
Proc ASCE v 89 n HY 3 May 1963 p 251-275

A summary review of the knowledge related to the mechanism of cavitation is presented. Stability criteria for a spherical gas nucleus as well as the possible origins of such nuclei are examined. The critical pressure for cavity instability depends on the type and size of nuclei present in the flow. This critical pressure in large hydraulic structures may usually be taken as the liquid vapor pressure, but for small models tested in laboratory facilities, the critical pressure can be much less than vapor pressure. For streamlined bodies with unseparated boundary layers, the conditions for cavitation inception may be predicted by setting the minimum boundary pressure equal to the critical pressure. This method is usually inadequate for the case of bodies with separated flows; however, a method of conservatively estimating the conditions for cavitation inception in separated flows is presented. The dynamics of a collapsing cavity are examined, and the influence of the boundary layer on the types of cavities formed and the resulting damage is also reviewed. The "scale effects" suggested by the mechanics of the cavitation process are presented

CAVITATION

J-10 Juliano, David W
REAERATION MEASUREMENTS IN AN ESTUARY
Proc ASCE v 95 n SA 6 Dec 1969 p 1165-1178

Measurements of surface reaeration are presented for the Sacramento-San Joaquin Delta. Estimates of reaeration were computed from observed diurnal dissolved oxygen changes in the estuary. The reaeration constants computed in this manner varied between 0.16 and 3.91 grams per cu m per hr at

BASIC STUDIES
estuaries
experimental

0-percent saturation. Independent in situ measurements using gasometric and disturbed equilibrium methods were conducted for comparison. Reaeration constants varied from 0.64 to 2.84 gm per cu m per hr using the gasometric method. The disturbed equilibrium method yielded reaeration constants between 0.62 and 1.70 gm per cu m per hr. The independent methods showed reaeration constants to be highly variable. Surface turbulence proved to be the most important mechanism controlling reaeration constants in the estuary. Wind velocity was the singularly most significant parameter in causing surface turbulence

K

K-1 Kalinske, A A
ECONOMIC EVALUATION OF AERATOR SYSTEMS
Environmental Sci Tech v 3 1969 p 229-234

In an illustrated article the author discusses the principles of design and operation of aerators and aeration systems, and describes methods for evaluating performance. (Water Pollution Abstracts)

EQUIPMENT
economics

K-2 Kalinske, A A
EVALUATION OF OXYGENATION CAPACITY OF LOCALIZED AERATORS
J Water Pollution Control Federation v 37 n 11 Nov 1965 p 1521-1529

Theoretical bases for techniques used to evaluate performance of aeration equipment are indicated, and conditions and limitations specified; it is shown that general theory that was developed for absorption of oxygen from air bubbles diffused into aeration basins is based on uniform conditions throughout any liquid volume under consideration; such conditions are not always obtained with localized aerators; therefore, relationships developed for uniform conditions must be used with care (EI 1966)

EQUIPMENT
waste treatment
diffusers

K-3 Kalinske, A A
SURFACE "AERATORS" FOR ABSORPTION AND DESORPTION OF GASES INTO WATER AND LIQUID WASTES
Water and Sewage Works v 115 n 1 Jan 1968 p 33-37

Problem of supplying oxygen and removal of carbon dioxide or hydrogen sulfide from water and waste water is discussed and several solutions are detailed; methods for calculation of necessary size of surface aerators, and retention times; aeration of flowing stream and removal of CO_2 from fixed volume of liquid and from flowing liquid (EI 1968)

EQUIPMENT
streams
waste treatment
mechanical aerators

K-4 Kalinske, A A Shell, G L Lash, L D
HYDRAULICS OF MECHANICAL SURFACE AERATORS
Water and Wastes Eng v 5 n 4 1968 p 65

EQUIPMENT
mechanical aerators

K-5 Kalman, L
ELECTROCHEMICAL MEASUREMENT OF THE OXYGEN CONTENT IN WATER, WASTE WATER, AND SLUDGE
Schweiz Z Hydrol v 31 n 1 1969 p 141-149

A newly developed apparatus for measuring oxygen concentrations is described. The apparatus works without any membrane, and no maintenance and readjustment is necessary even if it is used in activated sludge. The readings are only slightly affected by salt concentrations and pH of the medium. Practical experience with the use of the apparatus at the Horgen sewage treatment plant is reported. The application of the apparatus for continuous control of oxygen transfer in aeration basins by using different aeration systems is mentioned

DO ANALYSIS
instrumentation

K-6 Kaplovsky, A J Walters, W R Sosewitz, B
ARTIFICIAL AERATION OF CANALS IN CHICAGO
J Water Pollution Control Federation v 36 n 4 Apr 1964 p 463

EQUIPMENT
streams

K-7 Kaplovsky, A Joel — BASIC STUDIES; streams
discussion of CHANGES IN WASTE ASSIMILATION CAPACITY RESULTING FROM STREAMFLOW REGULATION by R. A. Vanderhoof
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 146-151

Gives a concise definition of assimilative capacity and questions the generally accepted concept that increased flow improves water quality; the important question is whether the loss of stabilization time within a given estuarine segment is sufficiently compensated by the lower concentration buildup level induced by an increase in flow

K-8 Kehr, Robert W — BASIC STUDIES; streams; experimental; reaeration; oxidation
MEASURE OF NATURAL OXIDATION IN POLLUTED STREAMS. IV. Effect of Sewage on Atmospheric Reaeration Rates under Flow Conditions
Sewage Works J v 10 n 2 1938 p 228-240

K-9 Kerri, K D — GENERAL
A DYNAMIC MODEL FOR WATER QUALITY CONTROL
J Water Pollution Control Federation
v 39 n 5 May 1967 p 772

K-10 King, D L — BASIC STUDIES; reservoirs; theoretical; experimental
HYDRAULICS OF STRATIFIED FLOW–SECOND PROGRESS REPORT–SELECTIVE WITHDRAWAL FROM RESERVOIRS
USBR Denver Colo Report No Hyd-595 Sep 1969

K-11 King, H R — EQUIPMENT; waste treatment
DESIGN OF AIR DISTRIBUTION SYSTEMS FOR ACTIVATED SLUDGE PLANTS
Water Works and Sewage v 91 1944

K-12 King, Henry R — EQUIPMENT; waste treatment; diffusers
MECHANICS OF OXYGEN ABSORPTION IN SPIRAL FLOW AERATION TANKS, EXPERIMENTAL WORK
Sewage and Ind Wastes v 27 n 9 1955 p 1007-1026

K-13 Kishinevski, M — BASIC STUDIES; theoretical; reaeration
TWO APPROACHES TO THE THEORETICAL ASPECTS OF GAS ABSORPTION
J of Applied Chem USSR Sep 1955 p 881 In Russian

K-14 Kitrell, F W — BASIC STUDIES; reservoirs; theoretical
EFFECTS OF IMPOUNDMENTS ON DISSOLVED OXYGEN RESOURCES
Sewage and Ind Wastes v 31 n 9 Sep 1959 p 1065-1078

Discusses the formation and persistence of stratification in reservoirs. Discusses stratification in impounded water, effects on dissolved oxygen, and theoretical energy requirements for mixing stratified reservoirs 1 to 25 kwhr/ac of surface per year. 30,000 acres, 1,500,000 acre-ft $5,850/yr

K-15 Kitrell, F W
THERMAL STRATIFICATION IN RESERVOIRS
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 57-76
Discusses temperature stratification in reservoirs, patterns of summer and winter stratification, and current tilted thermoclines

BASIC STUDIES
reservoirs

K-16 Kleijn, H F W
OXYGEN DEMAND NUMBER–NEW TOOL IN ESTIMATION OF OXYGEN DEMAND OF INDUSTRIAL AND DOMESTIC WASTE WATER
Air and Water Pollution v 10 n 8 Aug 1966 p 521-535
New system is evolved for calculation of theoretical oxygen demand that is particularly suited for evaluation of industrial waste water, but is valid as well in judgment of domestic waste and polluted water; amount of organic substances and in general oxidizable substances is expressed in carbon g-equivalent, which are so defined that elements nitrogen, sulfur, and phosphorus are equivalent with carbon; oxygen demand number of substance is number of g-equivalent oxygen needed for complete oxidation of one carbon g-equivalent of substance; this is derived from elemental composition. 24 refs (EI-1967)

BASIC STUDIES
waste treatment
theoretical
experimental
oxidation

K-17 Knight, W E
IMPROVEMENT OF THE QUALITY OF RESERVOIR DISCHARGES THROUGH CONTROL OF DISCHARGE ELEVATION
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 279-298
Discusses the concentration of dissolved oxygen in water discharged from a reservoir and selective level withdrawals from John H. Kerr Dam, Gaston Dam, and Roanoke Rapids Dam on the Roanoke River

BASIC STUDIES
reservoirs
experimental

K-18 Koberg, G E
ELIMINATION OF THERMAL STRATIFICATION BY AIR-BUBBLING TECHNIQUE IN LAKE WOHLFORD, CALIFORNIA
U S Geological Survey–Professional Paper 501-D 1964 p 190-192
Use of experimental air-bubbling system at Lake Wohlford, Calif., resulted in elimination of thermal stratification, definite improvement in taste and odor of water, and net reduction in evaporation of 35 acre-ft (5 percent) in 1962 (EI-1962)

EQUIPMENT
reservoirs
diffusers

K-19 Koberg, G E Ford, M E Jr
ELIMINATION OF THERMAL STRATIFICATION IN RESERVOIRS AND THE RESULTING BENEFITS
Geological Survey Water–Supply Paper 1809-M 1965
The use of air bubbling to artificially induce mixing in a lake has been successful in several investigations reported in the literature. A detailed study of this technique in Lake Wohlford in collaboration with the Escondido Mutual Water Co. of Escondido, Calif., is presented.

EQUIPMENT
reservoirs
diffusers

The results of the Lake Wohlford study indicate that the air-bubbling system is economically feasible to remove undesirable taste and odors from the water used for domestic purposes and to increase the dissolved-oxygen concentration in the hypolimnion of the lake. The results also indicate that the elimination of thermal stratification can reduce evaporation. The elimination of thermal stratification in Lake Wohlford during May, June, and July reduced the evaporation 15 percent. Although the evaporation was increased 9 percent in September, October, and November, the net reduction for the 6 months was about 6 percent.

The Lake Wohlford study and other tests cited have not presented enough data to define criteria for design of an air-bubbling system for a thermally stratified reservoir of a given capacity. Further studies are needed on larger reservoirs before design criteria can be established

K-20 Kolbe, F F
ARTIFICIAL OXYGEN REGENERATION AT GOREANGAB DAM
The Civil Engr of So Africa v 6 1964
Reports on use of air bubble gun to mix a reservoir to increase oxygen content

EQUIPMENT
reservoirs
hydraulic guns

K-21 Kothandaraman, V Ewing, B B
A PROBABILISTIC ANALYSIS OF DISSOLVED OXYGEN–BIOCHEMICAL OXYGEN DEMAND RELATIONSHIP IN STREAMS
J Water Pollution Control Federation v 41 1969 p R73-R90
Statistical analysis of the relation between dissolved oxygen and BOD in streams has shown that variations in the values of the deoxygenation and reaeration coefficients have a significant effect on the prediction of dissolved-oxygen level in polluted streams, and the error caused by the variations in these coefficients increases with increase in temperature. The most probable value for the oxygen deficit predicted by the probabilistic model using the Monte Carlo simulation techniques was found to be a better estimate than the values predicted by the conventional deterministic methods

BASIC STUDIES
streams
experimental
reaeration
oxidation

K-22 Krenkel, P A
TURBULENT DIFFUSION AND THE KINETICS OF OXYGEN ABSORPTION
PhD Thesis U of Calif 1960

BASIC STUDIES
streams
theoretical
experimental
reaeration

K-23 Krenkel, Peter A Orlob, Gerald T
TURBULENT DIFFUSION AND THE REAERATION COEFFICIENT
Proc ASCE v 88 n SA 2 Mar 1962 p 53-83
Reports on study of oxygen absorption as related to concepts of turbulent flow, explanation of mechanism causing transfer of oxygen into water, and development of a practical method of estimating oxygen transfer rates in open channel flow using easily obtained hydraulic parameters. Experimental reaeration coefficient and longitudinal mixing coefficient show a direct correlation between parameters when depth of flow is taken as a measure of eddy size. Transfer of oxygen molecules into a liquid is explained by the kinetic gas theory assuming only oxygen molecules with sufficient activation energy would be absorbed by the liquid

BASIC STUDIES
streams
theoretical
experimental
reaeration

K-24 Krenkel, P A Williams, H E
discussion to PREDICTION OF STREAM REAERATION RATES by M. A. Churchill
Proc ASCE J Sanitary Eng Div Apr 1963

BASIC STUDIES
streams
experimental
reaeration

K-25 Krenkel, Peter A Cawley, William A Minch, Virgil A
THE EFFECT OF IMPOUNDING RESERVOIRS ON RIVER WASTE ASSIMILATIVE CAPACITY
J Water Pollution Control Federation Sep 1965 p 1203-1217

Reduction of the waste assimilative capacity of reservoirs is mainly caused by inherent low DO in reservoirs, peaking power operations, and stratified flow conditions induced by cooling water discharge from a steam electrical generating plant. Studies were conducted on Coosa River, Ga. at the Georgia Kraft Mill, Mayos Bar, Weiss Reservoir, and Allatoona Reservoir

BASIC STUDIES
reservoirs
experimental

K-26 Krenkel, P A Thackston, E L Parker, F L
THE INFLUENCE OF IMPOUNDMENTS ON WASTE ASSIMILATIVE CAPACITY
Proc of the Speciality Conf on Current Res into the Effects of Reservoirs on Water Quality ASCE Portland Oreg Jan 1968

BASIC STUDIES
reservoirs
streams
theoretical
experimental
reaeration

K-27 Krishnamurthi, S Kumar, R Kuloor, N R
FORMATION OF BUBBLES
Chem and Process Eng v 49 n 1 Jan 1968 p 91-97, 100

Many operations, particularly distillation, require knowledge of sizes of bubbles; classical studies and models of bubble formation under constant flow conditions are examined, and new model is developed from empirical considerations, showing bubble volume (EI 1968)

BASIC STUDIES
bubbles
experimental

L

L-1 Lackey, Robert T — EQUIPMENT; reservoirs; diffusers

EFFECTS OF ARTIFICIAL DESTRATIFICATION ON PARVIN LAKE, COLORADO

Progress Report Project F-46-R-1 Colorado State University May 1970

Reports use of "Helixor" device for destratification of small lake to prevent winterkill of fish

L-2 Lamb, M — EQUIPMENT; diffusers

discussion of MECHANISM OF GAS ABSORPTION BY TURBULENT LIQUIDS by W. E. Dobbins

Proc 1st International Conf Water Pollution Res Pergamon Press Ltd London England v 2 1964 p 78

Contains description of transfer from bubbles originating from porous or nozzle diffusers. Shows efficiency advantage of porous type over nozzle type. Describes full-scale laboratory tests in which diffuser locations were varied

L-3 Langbein, W B Durum, W H — BASIC STUDIES; streams; experimental; reaeration

THE AERATION CAPACITY OF STREAMS

U S Geological Survey Circular No. 542 1967

Examines the variations in the coefficient of reaeration due to velocity, depth, and discharge of rivers; computations are made for the tons of oxygen per day that could be absorbed by the river for each unit of oxygen less than the saturation value

L-4 Landberg, G G Graulich, B P Kipple, W H — EQUIPMENT; mechanical aerators

EXPERIMENTAL PROBLEMS ASSOCIATED WITH THE TESTING OF SURFACE AERATION EQUIPMENT

Water Res v 3 n 6 Jun 1969

The method of testing surface aerators by unsteady-state reaeration of water at low or zero oxygen concentration is discussed and the assumptions made in applying the usual differential equation to calculate the mass-transfer coefficient are queried. Possible errors caused by the use of added chemicals to reduce the oxygen level, the existence of microscopically entrained gas bubbles, and the transport of gas bubbles to regions of significant hydrostatic pressures in deep tanks are pointed out. Test data obtained in various environmental conditions are described and discussed in relation to published work

L-5 Laughlin, J E — EQUIPMENT; waste treatment; misc equipment

STUDIES IN FORCE MAIN AERATION

Proc ASCE v 90 n SA 6 Dec 1964 p 13-24

Studies of an existing system showed air injection into a force main was an effective, economical, and reliable measure for controlling sulfides generation. Additional benefits included some degree of BOD reduction and removal of friction-producing bacterial filaments. Air at the force main outlet was not odorous, and contained only trace amounts of hydrogen sulfide. Generation of sulfides returned to normal levels a few days after aeration ceased. Analytical techniques used may apply elsewhere. The design rationale may be of value in other installations in which general conditions are similar

L-6 Leach, L E Duffer, W R Harlin, C C Jr — BASIC STUDIES; reservoirs; experimental

PILOT STUDY OF DYNAMICS OF RESERVOIR DESTRATIFICATION

Robert S. Kerr Water Res Center Ada Okla 1968

L-7 Leary, R D Ernest, L A Katz, W J
EFFECT OF OXYGEN TRANSFER CAPABILITIES AND WASTE WATER TREATMENT PLANT PERFORMANCE
J Water Pollution Control Federation v 40 n 7 Jul 1968 p 1298-1310
Performance of Jones Island Waste Water Treatment Plants, Milwaukee, Wis., were reduced because of inadequate oxygen transfer capabilities at one plant and because of introduction of poor waste-activated sludge from the plant into another plant. The spiral-flow aeration basin gave the lowest oxygen transfer of seven patterns tested; the ridge-and-furrow placement was the most efficient oxygen diffuser system

EQUIPMENT
waste treatment
diffusers

L-8 Le Bosquet, M Jr
discussion of THE OXYGEN SAG AND DO RELATIONSHIPS IN STREAMS by H. W. Streeter
Oxygen Relationships in Streams Tech Report W58-2 Robert A Taft Sanitary Eng Eng Center U S Public Health Service

BASIC STUDIES
streams
experimental
reaeration
oxidation

L-9 Lee, W S
discussion of IMPROVEMENT OF THE QUALITY OF RESERVOIR DISCHARGES THROUGH TURBINE OR TAILRACE AERATION
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 308-312
Cites aeration experiments with Francis turbines at the Wylie Station plant on the Catawba River, S. C.; reaeration effectiveness depends upon the turbine characteristics, load being carried, the setting of the wheel above tailwater elevation, vacuum-breaker arrangement, and the shape and dimensions of the draft tube

EQUIPMENT
streams
turbine injection

L-10 Lemke, A A
FLOW OF AIR IN PIPES
Sewage and Ind Wastes v 24 1952 p 24

EQUIPMENT

L-11 Lewis Whitman
PRINCIPLES OF GAS ABSORPTION
Ind Eng Chem v 16 1924 p 1215-1220
Describes film theory of mass transfer

BASIC STUDIES
theoretical
reaeration

L-12 Li, P S West, F B Vance, W H Moulton, R W
UNSTEADY STATE MASS TRANSFER FROM GAS BUBBLES–LIQUID PHASE RESISTANCE
A I Ch E J v 11 n 4 Jul 1965 p 581-587
Theoretical basis for mass transfer from gas bubbles is important for predicting distillation and absorption efficiencies; liquid-phase, mass-transfer coefficients were determined for streams of bubbles in water, gases used were pure oxygen, 10 percent carbon dioxide in air, and 10 percent chlorine in air. 31 refs (EI 1965)

BASIC STUDIES
bubbles
theoretical
experimental

L-13 Li, W H
UNSTEADY DISSOLVED-OXYGEN SAG IN STREAM
Proc ASCE v 88 n SA 3 May 1962 p 75-85
Solution is obtained for distribution of dissolved oxygen in polluted water of stream in which volume and velocity of flow are steady at any cross section,

BASIC STUDIES
streams
theoretical
reaeration

but not necessarily uniform at all cross sections; solution can account for added discharge and pollution along course of streams; in addition, unsteady distribution of dissolved oxygen due to unsteady initial oxygen content and BOD load can be computed (EI 1962)

L-14 Liebman, J C Lynn, W R — BASIC STUDIES; streams
THE OPTIMAL ALLOCATION OF STREAM DISSOLVED OXYGEN
Water Resources Res v 2 1966 p 581
Chem Abstracts v 66 1967 p 1359

L-15 Lin, T J Donnelly, H G — EQUIPMENT; cascades
GAS BUBBLE ENTRAINMENT BY PLUNGING LAMINAR LIQUID JETS
A I Ch E J v 12 n 3 May 1966 p 563-571
Investigation of factors affecting air entrainment process of free, liquid jet plunging into pool of same liquid; entrainment only occurs when average jet velocity exceeds certain value called minimum entrainment velocity; correlation of Weber numbers and Reynolds numbers which permits prediction of minimum entrainment velocity was developed; relevant to pouring of molten glass or polymer solutions, and paint, food, detergent, cosmetics, and pharmaceutical industries. 14 refs (EI 1966)

L-16 Londong, D — EQUIPMENT; streams
FLUBWASSERBELUFTUNGEN AN DER LIPPE (River Water Aeration on the Lippe)
Gewasserschutz-Wasser-Abwasser Band 1 Aachen 1968

L-17 Loucks, D P Lynn, W R — BASIC STUDIES; streams; theoretical
PROBABILISTIC MODELS FOR PREDICTING STREAM QUALITY
Water Resources Res v 2 1966 p 593
Chem Abstracts v 66 1967 p 1359

L-18 Loucks, D P Revelle, C S Lynn, W R — BASIC STUDIES; streams; theoretical; reaeration; oxidation
LINEAR PROGRAMMING MODELS FOR WATER POLLUTION CONTROL
Management Sci v 14 n 4 Dec 1967 p B-166-81
Two linear programming models are presented for determining amount of waste water treatment required to achieve at minimum cost any particular set of stream dissolved oxygen standards within river basin; derived from generalized Streeter-Phelps differential equations used to describe rates of dissolved oxygen depletion and recovery of streams, these models are adaptable to any river basin configuration; they can be used not only in determining system costs for various quality standards but also for measuring cost sensitivity to changes in stream and waste-water flows and treatment facility location; example illustrates use of these models (EI 1968)

L-19 Love, S K — BASIC STUDIES; reservoirs; experimental; oxidation
RELATIONSHIP OF IMPOUNDMENT TO WATER QUALITY
J American Water Works Assoc v 53 n 5 May 1961 p 559-568
Describes oxygen depletion conditions in the hypolimnion of a reservoir

L-20 Love, S K Slack, K V
CONTROLS ON SOLUTION AND PRECIPITATION IN RESERVOIRS
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 97-128

Examines the environmental events bringing about encounters with water and new solid phases or between unlike water masses in reservoirs with a detailed discussion of the resulting chemical reactions

BASIC STUDIES
reservoirs

L-21 Lueck, B F Wiley, A J Scott, R H Wisniewski, T F
DETERMINATION OF STREAM PURIFICATION CAPACITY
Sewage and Ind Waste v 29 Sept 1957 p 1054

BASIC STUDIES
streams
experimental
reaeration

M-1 Mackenthun, K M
THE EFFECTS OF NUTRIENTS ON PHOTOSYNTHETIC OXYGEN PRODUCTION IN LAKES AND RESERVOIRS
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 205-220
Biological activity influences chemical parameters including dissolved oxygen; it is governed by temperature and stimulated by nutrients

BASIC STUDIES
reservoirs
experimental
photosynthesis

M-2 Malz, F Bischofsberger
UEBER DIE ANWENDUNG POROESER PASTIKMATERIALIEN ALS BELUEFTUNGSKOERPER IN BELEBUNGSANLAGEN
Gas- u Wasserfach v 102 n 44 Nov 1961 p 1197-1199
Use of porous plastic materials as aerators in activated sludge tanks; efficiency of porous polyvinylchloride or polyester foil in aeration of sewage water; data on loss of pressure depending on velocity of airflow; data on amount of introduced oxygen; plastic aerators can be easily cleaned; this is advantage as compared to ceramic aerators In German (EI 1962)

EQUIPMENT
waste treatment
diffusers

M-3 Mancy, K H Okun, D A
EFFECTS OF SURFACE ACTIVE AGENTS ON AERATION
Water Pollution Control Federation J v 37 n 2 Feb 1965 p 212-227
Study was conducted to analyze theoretically and experimentally effect of surface active agents (SAA) on oxygen transfer kinetics; effect of SAA on oxygen transfer from air to water was studied in aeration vessels of different geometry in which water was stirred at various speeds; gas transfer was postulated as encountering total resistance composed of sum of two main resistances in series, liquid surface resistance and liquid bulk resistance; resistance to gas transfer was defined as being equal to reciprocal of rate constant. 36 refs (EI 1965)

BASIC STUDIES
waste treatment
experimental
reaeration

M-4 Manczak, H
VERBESSERUNG DER SAUERSTOFFVERHALTNISSE EINES GEBIRGSBACHES MITTELS SOHLENABSTAFFELUNG
(Improving the Oxygen Content of a Mountain Stream by Means of Steps in the Bed)
Osterreichische Wasserwirtschaft 1964 Heft 9/10 In German

EQUIPMENT
streams
cascades

M-5 Manzack, H
THE COURSE OF SELF-PURIFICATION PROCESS OF CANALIZED HIGHLY POLLUTED RIVERS
Water Res v 2 n 1 Jan 1968 p 3-4
A study to establish the capacity of self-purification in channeled and unchanneled sections of Odra River, Poland is described. Hydrographic, hydrometric, chemical, and biological measurements in the river showed: (1) ice cover reduced the biochemical processes; (2) the coefficient of oxygen utilization in polluted water was about half that from unpolluted water; (3) this coefficient decreased sharply during the navigable period; (4) the reaeration process was much lower in channeled section of the river than in unchanneled sections; (5) the self-purification capacity was relatively high in unchanneled sections, without ice; (6) the self-purification coefficient decreased in polluted water during summer and autumn only in the areas with high initial BOD values. It is concluded that canalization of Odra River has positive and negative features, of which the weirs which increase the amount

BASIC STUDIES
streams
experimental
reaeration
oxidation

of dissolved oxygen is the most important. The channel has negative effects such as accumulation of bottom sediment, hydrogen sulphide, and occurrence of oxygen deficiency

M-6 Marrucci, G Nicodemo, L
COALESCENCE OF GAS BUBBLES IN AQUEOUS SOLUTIONS OF INORGANIC ELECTROLYTES
Chem Eng Sci v 22 n 9 Sep 1967 p 1257-1265
Measurements of average bubble size in bubble column have been taken by means of photographic method; liquid phase consisted of aqueous solution of electrolyte and distributor was porous plate; number of different electrolytes were used, and superficial gas velocity was varied between 0.1 and 1.5 cm/sec; coalescence phenomena which occur near distributor; proposed correlation relates average bubble diameter to gas flow rate and to group of electrolyte properties. 38 refs (EI 1968)

BASIC STUDIES
bubbles
experimental

M-7 Maxworthy, T
NOTE ON EXISTENCE OF WAKES BEHIND LARGE, RISING BUBBLES
J Fluid Mechanics v 27 pt 2 Feb 1967 p 367-368
Using simple flow-visualization techniques, it was observed that as large volume of air rises through quiescent liquid it produced well-defined wake and that drag on bubble appears as momentum defect within this wake (EI 1967)

BASIC STUDIES
bubbles
experimental

M-8 McCloy, D
CAVITATION AND AERATION–EFFECT ON VALVES AND SYSTEMS
Hydraulic Pneumatic Power v 12 n 133-134 Jan 1966 p 32-37 Feb 1966 p 100-105
Conditions that give rise to cavitation and aeration and effects of their presence in hydraulic systems are discussed; orifice cavitation and cavitation erosion in valves are studied; theoretical analysis of cavitation occurrence in actuators during step and frequency responses is supported by experimental results (EI 1966)

CAVITATION

M-9 McDonnell, A J Hall, S D
EFFECT OF ENVIRONMENTAL FACTORS ON BENTHAL OXYGEN UPTAKE
Water Pollution Abstracts Proc 22nd Ind Waste Conf Purdue U Eng Extn Ser No 127 1967 p 414-428
Preliminary results of laboratory experiments on the effect of various factors on the oxygen demand of benthic deposits collected from Spring Creek, a highly eutrophic stream in Pennsylvania, confirmed that the rate of oxygen uptake is dependent on oxygen concentration and independent of sample depth. The presence of measureable densities of macroinvertebrates also has a marked effect, and an attempt was made by a relatively simple procedure to approximate the demands associated with microbial and invertebrate respiration to determine the relative importance of each

BASIC STUDIES
streams
experimental
oxidation

M-10 McDonnell, Archie J Kountz, R Rupert
ALGAL RESPIRATION IN A EUTROPHIC ENVIRONMENT
J Water Pollution Control Federation v 38 n 5 May 1966 p 841-857

BASIC STUDIES
streams
experimental
respiration

Present-day community development, especially in small watersheds, such as Spring Creek, Penn., has compounded problems of stream pollution criteria. In many stream situations, depletion of dissolved oxygen resources is a result not only of BOD but also of the effect of community respiration. Exactly how much effect each of these factors has on the dissolved oxygen level of the stream is difficult to evaluate. With statistical methods of regression and variance analysis, it was possible to define the BOD parameter as one of secondary engineering significance and to evaluate quantitatively the nocturnal oxygen demands of a heterogeneous stream flora. Community plant respiration varies directly with stream temperature and inversely with streamflow. Chemical analysis of contributing sources indicated nutrient concentrations sufficient to induce and maintain a eutrophic environment. On this basis, where population-to-receiving water resource ratio is high, analysis for significance of parameters other than BOD should be made and the findings manifested in the treatment process. The solution appears to lie in the removal of nitrogen and phosphorus from the waste water treatment plant effluent before it enters the creek waters, which practically implies total exclusion (Jones-Wis) W69-10159

M-11 McKinney, R E Benjes, H H Jr
EVALUATION OF TWO AERATED LAGOONS
Proc ASCE v 91 n SA 6 Dec 1965 p 43-55

EQUIPMENT
waste treatment
mechanical
aerators

Field studies of two aerated lagoons treating domestic sewage over 2-yr period yielded 63 percent BOD reduction with 1.7 days aeration and 78 percent BOD reduction with 7.1 days aeration; use of oxidation ponds after using aerated lagoons increased BOD reductions to 85 and 88 percent; it appeared that mechanical aerators-mixers could produce complete mixing with from 1/5 to 1/4 hp/1,000 cu ft aeration volume; bacterial cells were primarily responsible for effluent BOD from aerated lagoon; algae were responsible for effluent BOD from oxidation ponds (EI 1966)

M-12 McWhirter, J R
FUNDAMENTAL ASPECTS OF SURFACE AERATOR PERFORMANCE AND DESIGN
Purdue U–Eng Extn Ser 118 1965 p 75-92

EQUIPMENT
mechanical
aerators

Discussion of several methods for determination of oxygenation; unsteady-state reaeration is most widely used and accepted method; steady-state technique gives results about 10 percent higher than unsteady-state technique; sulfite oxidation data shows higher oxygen uptake rates than steady-state data with different temperature variation and significant variation in oxygen uptake rate with different catalysts. 24 refs (EI 1967)

M-13 Mercier, P Perret, J
AERATION STATION OF LAKE BRET
Monatsbull Schweiz Ver Gas- u Wasserfachm v 29 1949 p 25
Water Pollution Abstracts v 40 1950 p 533

EQUIPMENT
reservoirs
misc equipment

Attempts to aerate a stratified lake by withdrawing water, aerating, and returning to the same depth

M-14 Mercier, P Gay, S
EFFECTS OF ARTIFICIAL AERATION ON WATERS OF LAKE BRET
Rev Suisse d'Hydrologie v 16 1954 p 2
Reports on aerating water in a stratified lake by withdrawing water, aerating, and returning to same depth

EQUIPMENT
reservoirs
misc equipment

M-15 Metzger, I Dobbins, W E
THE ROLE OF FLUID PROPERTIES IN GAS TRANSFER
Environmental Sci and Tech v 1 1967 p 57

BASIC STUDIES
reaeration

M-16 Metzger, I
SURFACE EFFECTS IN GAS ABSORPTION
Environmental Sci and Tech v 2 1968 p 784

BASIC STUDIES
reaeration

M-17 Metzger, Ivan
EFFECTS OF TEMPERATURE ON STREAM AERATION
Proc ASCE v 94 n SA 6 Dec 1968 p 1153-1159
The effect of temperature on the aeration of receiving waters is often described by an equation of the form $K_T = K_{20}\,\theta^{(T-20)}$ where K_{20} is the 20^o value of the absorption coefficient and K_T is the value at some other temperature, T. In the past, θ has been considered to be a constant with various values assigned to it by different investigators. It is shown that θ is not a constant but depends on the level of turbulence and temperature. Values of θ appropriate for streams are determined by using the film penetration model and experimental results. These values are compared with values reported in the literature

BASIC STUDIES
streams
experimental
reaeration

M-18 Miyamoto, S
A THEORY OF THE RATE OF SOLUTION OF GAS INTO LIQUID
Bull Chem Society of Japan v 7 n 1 1932 v 7 n 12 Dec 1932 v 5 n 4 Apr 1930

BASIC STUDIES
theoretical
reaeration

M-19 Morgan, P F
MAINTENANCE OF FINE BUBBLE DIFFUSION
Proc ASCE v 84 n SA 2 Apr 1958
As a result of a 2-year laboratory study at the State University of Iowa, it has been confirmed that diffuser media can be clogged externally by a number of specific materials in the tank liquor, and internally by particulate matter in the air supply. Further, it was found that all forms of external clogging are aggravated by particulate matter in the air supply.

Corrective measures are proposed for each of the causes of clogging but because particulate matter is the most important it is recommended that it be corrected first. The commonly accepted standard for air quality of 0.5 mg/1,000 cu ft is shown to be unsatisfactory under certain conditions. A new standard of 0.1 mg/1,000 cu ft is proposed. Plant operating records are presented to show that a clogging problem was eliminated after the installation of precoated bag filters producing air meeting this standard. The corrective measures for other specific causes of clogging can be effectively applied only after the air supply is adequately filtered

EQUIPMENT
waste treatment
diffusers

M-20 Morgan P F Bewtra, J K
AIR DIFFUSER EFFICIENCIES
J Water Pollution Control Federation v 32 n 10 1960 p 1047

EQUIPMENT
diffusers

M-21 Morgan, P F Bewtra, J K
DIFFUSED AIR OXYGEN TRANSFER EFFICIENCIES
paper presented at Conference on Biological Waste Treatment Manhattan College 1960

EQUIPMENT
waste treatment
diffusers

M-22 Morgan, P F Bewtra, J K
DETERMINATION OF OXYGEN UPTAKE RATE BY POLAROGRAPH METHOD
J Water Pollution Control Federation v 34 1962

DO ANALYSIS
instrumentation

M-23 Morris, James S Krenkel, P A Thackston, E L
INVESTIGATIONS ON TURBULENT DIFFUSION IN INLAND WATERWAYS
Tech Report No. 14 Sanitary and Water Res Eng Vanderbilt U Nashville Tenn 1966

BASIC STUDIES
streams
experimental

M-24 Morris, J V McGill, L H Rutherford, C C
MECHANICAL AERATORS TESTED AT LONDON'S "GREENWAY" POLLUTION CONTROL CENTRE
Water and Pollution Control v 106 n 1 Jan 1968 p 30-32

Paper summarizes results of program of acceptance tests of mechanical aerators supplied at London, Ontario, sewage treatment facilities; work involved reconstruction and renovation of existing primary, aeration and final tanks to bring their capacity to 7 mgd; economic analysis indicated desirability of employing mechanical aerators to supply oxygen necessary for new activated-sludge secondary-treatment plant which would operate as third, parallel section of total works (EI 1968)

EQUIPMENT
waste treatment
mechanical aerators

M-25 Morris, R M
MASS TRANSFER AND BUBBLE SIZES IN SOLID-LIQUID-GAS SYSTEMS
Chem and Ind n 44 Oct 1964 p 1836-1837

Contacting of gas and liquid with suspended solids in vessel with rotating impeller; applicability to fermentation processes such as yeast and antibiotics manufacture, aeration of activated sewage sludge, and catalytic hydrogenation and chlorination reactions; of specific industrial interest is scrubbing of flue gases (10 percent CO_2) by means of calcium hydroxide slurry in agitated vessel, and precipitation of whiting for plastics and paint industries (EI 1965)

EQUIPMENT
waste treatment
misc equipment

M-26 Mortimer, C H
THE EXCHANGE OF DISSOLVED SUBSTANCES BETWEEN MUD AND WATER IN LAKES
J Ecol v 29 1941 p 280-329; v 30 1942 p 147-201

BASIC STUDIES
reservoirs
experimental

M-27 Muenz, K Marchello, J M
SURFACE MOTION AND GAS ABSORPTION
A I Ch E J v 12 n 2 Mar 1966 p 249-253

Influence of small waves on mass transfer from pure gases into water is investigated; small-amplitude progressive two-dimensional waves are

BASIC STUDIES
experimental
reaeration

mechanically generated at liquid surface for wave studies; control experiments with nonwaved surfaces are also conducted; effect of surface motion arising from Marangoni instability is considered for nonwaved surface; effective diffusivity is used to correlate data (EI 1966)

M-28 Murphy, G I
EFFECT OF MIXING DEPTH AND TURBIDITY ON THE PRODUCTIVITY OF FRESH-WATER IMPOUNDMENTS
Trans American Fisheries Society v 91 n 1 1962 p 69-76

BASIC STUDIES
reservoirs

N

N-1 Nems, E I Tokmakov, V I Chigareva, T S
O ZAVISIMOSTI FORMY POVERKHNOSTNYKH PUZYR'KOV (KAPEL) OF IKH RAZMERA
Akademiya Nauk Izvestiya Energetika i Transport n 2 Mar-Apr 1967 p 146-149
Shape of surface bubbles as dependent on their size; change of shape of bubbles during growth was studied; it is shown that base of growing bubble first crawls apart but later contracts until onset of breakoff. In Russian (EI 1968)

BASIC STUDIES
bubbles
experimental

N-2 Nesmeyanov, S.A
DONNYE OTLOZHENIYA I KILORODNYI REZHIM VODOEMOV
(Benthic Deposits and the Oxygen Regime of Reservoirs)
Izd-vo Akad Med Nauk USSR Moscow 1950 157 p In Russian

BASIC STUDIES
reservoirs
oxidation

N-3 Nicholas, W R Bewtra, J K
EFFECT OF SUBMERGENCE ON AERATION DEVICES IN OXGENATION IN AERATION TANKS
presented at the 35th Annual Meeting of the Central States Water Pollution Control Assoc Duluth 1962

EQUIPMENT
waste treatment

N-4 Nicholas, W R
AERATION SYSTEM DESIGN
presented to the Sanitary Eng Inst U of Wis Madison Wis 1965

EQUIPMENT
waste treatment
diffusers

N-5 Novak, R G
TECHNIQUES AND FACTORS INVOLVED IN AERATOR SELECTION AND EVALUATION
J Water Pollution Control Federation v 40 n 3 pt 1 Mar 1968 p 452-463
Methods, results, and data reliability obtained during in-place, steady-state evaluation of two different types of aeration equipment for chemical wastes are presented; oxygen transfer efficiency of installed system of mechanical aerators was estimated by measuring oxygen uptake and power; COD, BOD, sludge volume index, suspended solids, and mixed liquor velocity were evaluated (EI 1968)

EQUIPMENT
waste treatment
mechanical aerators

N-6 Novotny, V
ON THE DIFFUSION PHENOMENON IN BOUNDARY LAYERS OF TURBULENT FLOW AND ITS INFLUENCE ON THE COURSE OF SELF-PURIFICATION OF SMALL STREAMS
Water Res v 2 n 6 1968

BASIC STUDIES
streams
reaeration

O

O-1 O'Connell, R L Thomas, N A
EFFECT OF BENTHIC ALGAE ON STREAM DISSOLVED OXYGEN
Proc ASCE v 91 n SA 3 Jun 1965 p 1-16
The effects of respiratory oxygen uptake by photosynthetic benthos on the water quality of streams is examined. Methods for evaluating these effects are given together with results obtained in a survey of the Truckee River. The signficance of daily minimum dissolved oxygen concentrations in streams is considered and techniques for prediction of this value incorporating benthic algal effects are described

BASIC STUDIES
streams
experimental
respiration

O-2 O'Connor, D J Dobbins, W E
THE MECHANISM OF REAERATION IN NATURAL STREAMS
Proc ASCE v 82 n SA 6 1956 p 1115
Develops a theoretical model for reaeration of a turbulent system

BASIC STUDIES
streams
theoretical

O-3 O'Connor, D J
THE MEASUREMENT AND CALCULATION OF STREAM REAERATION RATIO
Oxygen Relationships in Streams Tech Report No. W-58-2 Taft Sanitary Eng Center 1958

BASIC STUDIES
streams
experimental
reaeration

O-4 O'Connor, D J
OXYGEN BALANCE OF AN ESTUARY
Proc ASCE v 86 n SA 3 May 1960
The net seaward movement of organic impurities in estuaries is due to the displacement by the land runoff and to the longitudinal diffusion of the tidal action. The dissolved-oxygen profile depends on the concentration of the organic materials, its rate of oxidation, and the resulting rate of reaeration. The interrelationship among these geophysical and biochemical factors is described by a differential equation under a steady-state condition. The assumption of constant coefficients in the equation is confirmed by the field data from estuarine surveys of the Delaware and the James Rivers. Dissolved-oxygen profiles are calculated from the integrated equation and compared to the measured dissolved-oxygen concentrations. The turbulent diffusion coefficient and the deoxygenation rate are determined from an analysis of survey data and are used in the calculation of the oxygen profiles. The agreement between the calculated profiles and the observed values is sufficiently close to justify the use of the equations for the conditions assumed in the development

BASIC STUDIES
estuaries
theoretical
experimental

O-5 O'Connor, D J
TEMPORAL AND SPATIAL DISTRIBUTION OF DISSOLVED OXYGEN IN STREAMS
Water Resources Res v 3 n 1 First Quarter 1967 p 65-79
Geophysical characteristics of drainage basin and biochemical and physical environment of river affect concentration of dissolved oxygen, these factors are embodied in fundamental equation of continuity that describes oxygen balance, variation of fresh-water flow and cross-sectional area is included, as well as various sources and sinks of oxygen—natural and artificial aeration, photosynthetic contribution, bacterial and algae respiration, carbonaceous and nitrogenous oxidation, and benthal deposits (EI 1967)

BASIC STUDIES
streams
reaeration
oxidation

O-6 Ogunrombi, J A
THE EFFECTS OF BENTHAL DEPOSITS ON THE OXYGEN RESOURCES OF NATURAL STREAMS
Water Pollution Abstracts thesis New York U 1968
Dissertation Abstracts v 29 n B 1969 p 3343

BASIC STUDIES
streams
experimental
oxidation

Benthal deposits are known to exert oxygen demands on the overlying water, and it is suggested that this occurs in two ways—by addition of organic matter from the deposits, to the water, thus increasing the BOD of the water; and by the removal of dissolved oxygen from the water to satisfy both the BOD of organic matter in the top aerobic layer and the intermediate COD of products of anaerobic decomposition which diffuse to the aerobic zone from the deeper layers. Laboratory experiments were carried out to verify the existence of these processes and the results indicated that the rate of transfer of organic matter from the benthal deposits to the supernatant water is smaller than the rate at which dissolved oxygen is abstracted from the water by the deposits. For any sludge depth, the total oxygen demand of the deposit is less than the potential aerobic demand of the sludge

O-7 Oldaker, W H Burgun, A A Pahren, H R
PILOT-PLANT STUDY OF BENTHIC OXYGEN DEMAND OF RIVER BOTTOM SEDIMENTS
J Water Pollution Control Federation v 40 n 10 Oct 1968 p 1688

BASIC STUDIES
streams
oxidation

O-8 Orlob, G T
EDDY DIFFUSION IN HOMOGENEOUS TURBULENCE
Proc ASCE v 85 n HY 9 Sept 1959 p 75-103

BASIC STUDIES
streams

O-9 Owens, M Edwards, R W Gibbs, J W
SOME REAERATION STUDIES IN STREAMS
Air and Water Pollution v 8 n 8-9 Sept 1964 p 469-486

BASIC STUDIES
streams
experimental
reaeration

Reaeration coefficients of several reaches of lowland and lake district streams were determined and correlated with some of hydraulic characteristics of streams to see if observed reaeration coefficients agree with those calculated from equations proposed by previous workers; empirical equation is derived from which it is possible to predict reaeration rate which could be expected in rivers from their mean velocities and depths, provided these are within experimentally observed ranges. 27 refs (EI 1965)

O-10 Owens, M Knowles, G
THE PREDICTION OF THE DISTRIBUTION OF DISSOLVED OXYGEN IN RIVERS
Water Res v 2 1968 p 20

BASIC STUDIES
streams
reaeration

P

P-1 Palladino, A J — EQUIPMENT; streams; turbine injection; diffusers

INVESTIGATION OF METHODS OF STREAM IMPROVEMENT

Ind Water and Wastes v 6 n 3 1961 p 87

Includes evaluation of turbine venting and diffusers for reaeration of Kalamazoo River in Michigan. The stream is heavily polluted with paper mill wastes. Turbine venting added 2 lb/kwhr, with initial DO less than I mg/l. 0.5 mg/l was added through venting. Vent noise indicated undersizing. Drilled pipe diffusers resulted in 1 mg/l pickup with airflow of 570 cfm, or 0.6 mg/l at 325 cfm. Efficiency thus was 1.6 to 1.7 percent, or about 0.5 lb/kwhr. Initial DO was 2 to 3 mg/l

P-2 Panaiotti, S S — CAVITATION

VLIYANIE RASTVORENNOGO V ZHIDKOSTI GAZA NA KAVITATSIONNYE KHARAKTERISTIKI

Izvestiya Vysshikh Uchebnykh Zavedenii Mashinostronie n 4 1968 p 95-100

Influence of gas dissolved in liquid upon cavitation characteristics; cavitating flows around cylindrical profile were examined for cases of water-air and water-carbon-dioxide systems; it was found that variations of gas content in water have no practical effect on values of characteristic coefficients of cavitation; applicable to cavitation in pumps. In Russian (EI 1968)

P-3 Parker, Frank L — BASIC STUDIES; reservoirs; experimental

EDDY DIFFUSION IN RESERVOIRS AND PIPELINES

Proc ASCE v 87 n HY 3 May 1961 p 151-171

Ocean eddy current diffusion coefficient is a function of eddy size, which is confirmed by reservoir tests with radioactive tracers. Tests of eddy diffusion in pipelines are compared with Taylor's solution; pipeline coefficients are greater because of obstructions and curved sections in the pipe

P-4 Pasveer, A — EQUIPMENT; waste treatment

A STUDY OF THE AERATION OF WATER

Res on Activated Sludge I Sewage and Ind Wastes v 25 n 11 Nov 1953 p 1253

P-5 Pasveer, A Sweeris, S — EQUIPMENT; waste treatment; diffusers

NEW DEVELOPMENT IN DIFFUSED AIR AERATION

J Water Pollution Control Federation v 37 n 9 Sept 1965 p 1267-1274

Application of study on oxidation-ditch system for purification of smaller quantities of domestic and industrial wastes to investigate whether it is possible to use diffused-air system in horizontal flow of mixed liquor, steel ring-shaped aeration tank was constructed in which it was possible to achieve horizontal flow by paddle-wheel arrangement; experiments were performed at various velocities of horizontal flow; quantity of oxygen taken up per 100 cm of water-column was determined as percentage from weight of oxygen introduced with air (EI 1966)

P-6 Pasveer, A — EQUIPMENT; waste treatment; diffusers

CONSIDERATIONS ON EFFICIENCY OF AERATION PROCESS

Air and Water Pollution v 10 n 8 Aug 1966 p 477-493

Possibility of achieving higher efficiencies in aeration processes than are achieved in practice is considered; according to theory of aeration, besides creation of large interface of water and air, rapid renewal of this interface is also of great importance; it is found that in methods of diffused air aeration, only 10 percent of gross energy expended is used for surface creation and surface renewal; improvement in diffused air efficiency could be achieved by avoiding "spiral flow" and "ridge and furrow" systems by means of "horizontal flow" system and by using smaller air bubbles. 26 refs (EI 1967)

P-7 Patriarche, Mercer H
AIR-INDUCED WINTER CIRCULATION OF TWO SHALLOW MICHIGAN LAKES
J Wildlife Management v 26 1961 p 289

EQUIPMENT
reservoirs
diffusers

P-8 Patterson, Calvin C Gloyna, Earnest F
DISPERSION MEASUREMENT IN OPEN CHANNELS
Proc ASCE v 91 n SA 3 Jun 1965

BASIC STUDIES
streams
experimental

P-9 Pence, G D Jeglie, J M Thomann, R V
TIME-VARYING DISSOLVED OXYGEN MODEL
Proc ASCE v 94 n SA 2 1968 p 381

BASIC STUDIES
streams
reaeration

P-10 Pearson, E A
discussion of THE MEASUREMENT AND CALCULATION OF STREAM REAERATION RATIO by D. J. O'Connor
Oxygen Relationships in Streams Tech Report No. W-58-a2 Taft Sanitary Eng Center 1958

BASIC STUDIES
streams
experimental
reaeration

P-11 Peskin, R L
LAWS OF DISPERSION
Water Resources Research Institute Report Rutgers Univ Oct 1969

Two problems on the laws of dispersion for materials such as small particles and gas bubbles in turbulent streams are considered. After discussing the mechanisms of single-particle dispersion, a statistical approximation model is used to calculate two-particle dispersion. Specifically, the Eulerian fluid velocity which appears in the equation of motion of a small particle is replaced by a random best estimate. This estimate is obtained by prediction techniques using specified statistical properties of the turbulence field. The second problem considered is that of gas bubble dispersion. An approximate analysis is used to estimate the spread of bubbles from a line source of bubbles. Buoyancy and turbulence inhomogeneity effects, which result in a bubble size segregation, are evaluated

BASIC STUDIES
theoretical
reaeration

P-12 Pfeffer, John T
EVALUATION OF AERATOR CAPABILITIES FOR WASTE WATER TREATMENT
Tappi v 52 n 9 1969 p 1652-1655

Studies of aeration systems have shown a need for evaluation of aeration equipment operating under field conditions. Procedures have been developed for rating aerators, by using clean water as standard test conditions. Studies of the effects of waste water characteristics have shown that the oxygen transfer capacity of an aeration system can be significantly changed from the rated capacity. These effects are discussed and related to industrial waste water flows, particularly pulp and paper. Techniques for evaluation of systems operating under field conditions have been developed. These techniques are discussed and results of field studies are presented. Procedures for the determination of correction factors are given

EQUIPMENT
waste treatment

P-13 Pfeffer, J T Hart, F C Schmid, L A
FIELD EVALUATION OF AERATORS IN ACTIVATED SLUDGE SYSTEMS
Water and Sewage Works v 115 1968 p 520

EQUIPMENT
waste treatment

P-14 Phelps, E B
STREAM SANITATION
John Wiley and Sons, Inc New York N Y 1944

BASIC STUDIES
streams
reaeration

P-15 Plateau, J A F
STATIQUE DES LIQUIDS
Paris 1873 v 1 c 5

Presents the laws of bubble geometry based on minimizing surface area of liquid films; the laws are: 3, and only 3, foam lamellae meet at an edge—the 3 coplanar angles at which they are inclined to each other are all equal, each is 120° In French

BASIC STUDIES
bubbles
theoretical

P-16 Poon, C P C
THEORETICAL CONCEPT OF OXYGEN TRANSFER IN GAS BUBBLE AERATION SYSTEM
Water and Sewage Works v 113 Nov 30 1966 p R200-202 204-205

Proposed theory and mathematical treatment of gas transfer process is presented with statistics of molecular motion and turbulent diffusion; single gas-liquid boundary layer is considered instead of two films which have been generally accepted as controlling factors; readily soluble gas is one which as high α-value, specifying fraction of gas molecules striking bubble wall and condense; therefore thickness of liquid film—turbulent diffusion zone in this theory, controls rate of absorption since it will be slower step; on the other hand, less soluble gas will be limited by thickness of gas-film, α-value in theory, and not by liquid film; proposed theory is more direct and easier to be followed (EI 1967)

BASIC STUDIES
bubbles
theoretical

P-17 Poon, C P C Campbell, H
DIFFUSED AERATION IN POLLUTED WATER
Water and Sewage Works v 114 n 12 Dec 1967 p 461-463

Effect of dissolved chemicals in water on transfer process was studied in series of experiments; pyrex column of 5-1/2 in ID was built 12 feet high measured from top of diffusers to top of column; fritted glass diffusers were installed at bottom of column; temperature of water in column for all experiments was automatically held constant using thermostat with immersion heater; experiments were run at water depth of 7.0 ft above top of diffuser and rate of airflow was maintained at constant of 300 cc/min; temperature was held constant at 20° C or otherwise diffusion coefficient was corrected to 20° C. 10 refs (EI 1968)

EQUIPMENT
diffusers

P-18 Poon, C P C Lee, F
SURFACE AERATION BY MECHANICAL AGITATION
Water and Sewage Works v 116 n 7 Jul 1969 p 262

In experiments with mechanical aeration in laboratory-scale circular tanks, various factors affecting the oxygen absorption coefficient were studied, including the degree of submergence of the rotor blades, rotor speed, and water depth. The overall oxygen absorption coefficient increase significantly with increasing rotor size at high speeds

EQUIPMENT
mechanical aerators

P-19 Poston, H W Ownbey, C R | GENERAL

THE GREAT LAKES WATER RESOURCE

J American Water Works Assoc v 60 n 1 Jan 1968 p 15-20

The problems of eutrophication, increase of chemicals, and oxygen depletion are discussed. Measures presently being taken are presented, including Federal grants. Legally, the judicial process has been inadequate to resolve the problems created by the conflicting interest for the use of the water. The Great Lakes belong to all the people of the United States and Canada, but the problem is who should be the custodian of these waters. A Board of Directors, similar to that governing the Tennessee Valley Authority, is proposed. The representation of the states bordering the Great Lakes, the Province of Ontario, and the Governments of the United States and Canada is discussed

P-20 Purdy, R W | BASIC STUDIES

WHAT DO WE KNOW ABOUT NATURAL PURIFICATION? | streams

Proc ASCE v 94 n SA 1 Feb 1968 p 1-11 | reaeration

It is possible to predict effect of stabilization of oxidizable substances on DO content of stream; time of flow can be calculated on basis of displacement of occupied channel volume but calculations should be checked by observing time of passage with fluorescent dye; effect of sludge deposits, biological extraction and accumulation, and oxidation of nitrogenous substances on DO balance in stream can be evaluated and examples of such evaluations are presented. 11 refs (EI 1968)

Q

Q-1 Quigley, J T
EFFECTIVENESS AND COSTS OF VARIOUS TYPES OF MECHANICAL REAERATION FOR RIVERS AND IMPOUNDMENTS
Unpublished paper presented to the Seminar in Water Resources Planning
U of Wis Madison Wis Apr 1969

Describes problem of generalizing four alternative aeration systems for purposes of cost comparison: (1) porous diffuser system, (2) perforated tubing system, (3) mechanical surface aerator, and (4) hydraulic turbine injection

EQUIPMENT
streams
reservoirs
turbine injection
diffusers
mechanical aerators
economics

Q-2 Quirk, T P Eder, L J
EVALUATION OF ALTERNATIVE SOLUTIONS FOR ACHIEVEMENT OF RIVER STANDARDS
J Water Pollution Control Federation v 42 n 2 pt 1 1970 p 272

A river of approximately 170 miles (274 km) in length and 3,500 sq miles (9,965 sq km) in drainage area is studied. The purpose of the study was to: determine the physical characteristics, develop a mathematical simulation model to predict BOD and DO profiles under any condition of flow, temperature, or waste discharge, and application of the model to investigate BOD assimilation capacity under critical weather and flow conditions. The effects of sludge deposits, hydroturbine venting, and flow augmentation are determined. The model also was used to determine the comparative economics of alternative solutions for the achievement of proposed water-quality standards. The effects of channel geometry, sludge composition, location, depth, oxygen uptake rates, point aeration, riverflow, and seiche wave effect were plugged into the model. Seven solution components were analyzed and the results, used by regulatory personnel and industry, culminated in the establishment of a common basis for interpretation of the financial requirements and practical capability of achieving various levels of water quality improvement

BASIC STUDIES
streams
theoretical
experimental
reaeration
oxidation
EQUIPMENT
turbine injection

R

R-1 Ragone, Stanley Peters, B J

WATER QUALITY MONITORING FOR WATER QUALITY CONTROL

U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 1965

Describes submerged weirs at Gaston Dam and Roanoke Rapids Dam designed to prevent discharge of cold, oxygen-deficient water; weirs skim off oxygen-rich surface layers of water and prevent density currents from entering intakes

BASIC STUDIES
reservoirs
experimental

R-2 Rasmussen, D H

PREVENTING A WINTERKILL BY USE OF A COMPRESSED AIR SYSTEM

Progressive Fish Culture v 24 1960 p 185

Reports on compressed air mixing of lakes to prevent fish winterkill when the lake freezes over and cuts off the oxygen supply

EQUIPMENT
reservoirs
diffusers
misc uses

R-3 Redfield, J A Houghton, G

MASS TRANSFER AND DRAG COEFFICIENTS FOR SINGLE BUBBLES AT REYNOLDS NUMBERS OF 0.02-5000

Chem Eng Sci v 20 n 2 Feb 1965 p 131-139

Simultaneous dilatometric and photoelectric determinations of mass transfer and velocity of rise, respectively, have been made for a single bubbles of CO_2 rising in pure water and aqueous solutions of dextrose; although boundary layer and potential flow models predict orders of magnitude and general trends for drag and mass-transfer coefficients at Re greater than 1, detailed comparison is masked by changes in shape and motion of bubbles as well as presence of turbulence in wake. 35 refs (EI 1965)

BASIC STUDIES
bubbles
experimental

R-4 Reid, L C Jr

AERATED SEWAGE LAGOON IN ARCTIC ALASKA

Western Canada Water and Sewage Conf 17th Annual Convention—Papers Sep 15-17 1965 p 101-113

Observations and results of study conducted by Arctic Health Research Center, with cooperation of Air Force of Alaskan Air Command, during winter of 1964-65 on aerated sewage pond receiving settled domestic sewage at Eielson Air Force Base; pond is located 25 miles from Fairbanks, in central valley of Alaska area which ordinarily experiences coldest winter temperatures in United States; Air-Aqua System provides aeration and lagoon operates on extended aeration principle; rising action of air bubbles divides lagoon into 15 individual cells which are continually being mixed; activated sludge agglomerates until particles are too large to remain in suspension, whereupon it settles and digests on lagoon floor (EI 1967)

EQUIPMENT
waste treatment
diffusers

R-5 Revelle, C S Loucks, D P Lynn, W R

LINEAR PROGRAMMING APPLIED TO WATER QUALITY MANAGEMENT

Water Resources Res v 4 n 1 1968 p 1

GENERAL

R-6 Revelle, C S Loucks, D P Lynn, W R

A MANAGEMENT MODEL FOR WATER QUALITY CONTROL

J Water Pollution Control Federation v 39 n 7 Jul 1967 p 1164

GENERAL

R-7 Riddick, Thomas M
FORCED CIRCULATION OF RESERVOIR WATERS
Water and Sewage Works v 104 n 6 1957 p 231-237
Compressed air mixing of 246 acre-ft reservoir at Ossining, N. Y. completely destratified and recirculated the water almost twice a day

EQUIPMENT
reservoirs
diffusers

R-8 Rincke, G Moeller, U
MESS- UND VERFAHRENSTECHNISCHE MOEGLICHKEITEN FUER EINE AUTOMATISCHE REGELUNG DER SAUERSTOFFZUFUHR IN BELUEFTUNGSBECKEN
Vom Wasser v 34 1967 p 297-333
Measurement and technical process possibilities for automatic control of oxygen supply to aeration basins; literature revew of devices for analysis of oxygen contents in aeration basins; first continuous analyzer and controller by G. Stracke is described; effects of various parameters on devices sensitivity, accuracy of commercial-scale tests, and results. 38 refs. In German (EI 1968)

DO ANALYSIS
instrumentation

R-9 Robertson, J M
CAVITATION IN HYDRAULIC STRUCTURES: SCALE EFFECTS INVOLVED IN CAVITATION EXPERIMENTS
Proc ASCE v 89 n HY 3 May 1963 p 167-180
The general nature and purpose of experimental studies of cavitation-susceptible hydraulic structures is reviewed. Scale effects are defined as deviations in the cavitation occurrences from the simple concept of cavitation in a liquid of given density and vapor pressure, resulting from other fluid properties and occurrences. For simple bodies, known scale effects are shown to be characterized sometimes by the Reynolds number and sometimes by a dimensional parameter $V\sqrt{d}$. The effects of protuberances or roughnesses in terms of boundary-layer thickness and location on the body are indicated as potential sources of large effects. Possible effects of air content on cavitation scaling are also noted

CAVITATION

R-10 Roe, F C
THE INSTALLATION AND SERVICING OF AIR DIFFUSER MEDIUMS
Water and Sewage Works v 81 1934 p 450

EQUIPMENT
diffusers

R-11 Rolley, H L J Owens, M
OXYGEN CONSUMPTION RATES AND SOME CHEMICAL PROPERTIES OF RIVER MUDS
Water Res v 1 1968 p 759
Rates of oxygen consumption varying from 0.006 to 0.41 $g/m^2/hr$ were obtained during an investigation of sediments collected from 74 sites in 12 river systems during January-February and July-August 1966. The distribution of these rates was similar in both surveys and no correlation was found between rates of oxygen consumption and any chemical property of the mud. Strong correlations were obtained between all the chemical properties examined: permanganate value, loss on ignition, and contents of humic acid, org. C, and Kjeldahl N. Deposits in reaches below outfalls from sewage-treatment works operating percolating filters to a nominal effluent standard of 30 mg/l suspended solids and 20 mg/l BOD were not found to differ significantly from those in unpolluted reaches. However, both were significantly different from deposits downstream of outfalls from works using the activated sludge process

BASIC STUDIES
streams
experimental
oxidation

R-12 Ross, Sydney
BUBBLES AND FOAM
Ind and Eng Chem v 61 n 10 Oct 1969 p 48-55
The general law of bubble geometry takes into account the minimizing of surface area required to contain a given amount of gas at a given temperature and given pressure

BASIC STUDIES
bubbles
theoretical

R-13 Rozen, A M
PROBLEMY TEORII I INZHENERNOGO RASCHETA PROTESESSOV MASSOOBMENA
Khimicheskaya Promyshlennost n 2 Feb 1965 p 5-11
Problems of theoretical studies and engineering calculations of mass exchange processes; development of theory of mass exchange; measurements and calculations of contact surface in liquid-gas and liquid-liquid systems; theory of scalar transitions concerned with transversal irregularity in large-diameter apparatus. In Russian (EI 1966)

BASIC STUDIES
theoretical
reaeration

R-14 Ruckenstein, E
A GENERALIZED PENETRATION THEORY FOR UNSTEADY CONVECTIVE MASS TRANSFER
Chem Eng Soc (Brit) v 23 n 4 1968 p 363

BASIC STUDIES
theoretical
reaeration

R-15 Ryder, Robert A
DISSOLVED OXYGEN CONTROL IN ACTIVATED SLUDGE
Ind Water Eng v 6 n 9 1969 p 43-45
The control of the dissolved oxygen concentrations in activated sludge to ± 0.2 percent mg/l results in a continuous response to changing oxygen demands, reduced power consumption, and suppression of filamentous organism growth (sludge bulking). The volume of air directed to three aeration tanks and a post-aeration tank was regulated by butterfly valves responsive to both waste and dissolved oxygen content. The aeration pattern was varied to match the desired aeration profile by adjusting the number of diffusers on each swing header. Sludge bulking was decreased when the dissolved oxygen levels were kept at 0.75 to 1.0 and 0 mg/l in the aeration and sedimentation tanks, respectively. Rohm and Haas (C-7) polyelectrolyte increased the zone settling rate by a factor of 10 in the laboratory and afforded immediate relief to sludge bulking until a stable sludge was obtained by dissolved oxygen control

EQUIPMENT
waste treatment
diffusers

S

S-1 Schade, W F Wirts, J J
DIFFUSER PLATE CLEANING VERSUS COMPRESSED AIR COST
Sewage Works J v 14 1942 p 81

EQUIPMENT
diffusers
economics

S-2 Schmitz, William R Hasler, Arthur D
ARTIFICIALLY INDUCED CIRCULATION OF LAKES BY MEANS OF COMPRESSED AIR
Sci v 128 1958 p 1088

EQUIPMENT
reservoirs
diffusers

S-3 Schrock, V E Perrais, J P
DYNAMICS OF BUBBLES IN KNOWN TEMPERATURE DISTRIBUTION
Heat Transfer and Fluid Mechanics Inst 19th—Proc Jun 22-24 1966 p 122-147

Experimental investigation of bubble growth rates and shapes was conducted using system in which thermal environment is known; this was accomplished by viewing from two directions those bubbles which were first nucleated on transiently heated surface; to vary thickness of superheated liquid layer and steepness of temperature profile at time of nucleation, subcooling, pool pressure, and heating schedule were varied appropriately; this produced superheat thicknesses ranging from 2 to 12 mils while maximum bubble size ranged from 12 to over 110 mils; shape factors were defined and determined over bubble lifetime. 24 refs (EI 1967)

BASIC STUDIES
bubbles
experimental

S-4 Scott, W Foley, A L
A METHOD OF DIRECT AERATION OF STORED WATERS
Reprinted from Proceedings of the Indiana Academy of Science for 1919, Aug 1921

Describes very early application of diffusers to reaeration of a small reservoir

EQUIPMENT
reservoirs
diffusers

S-5 Scott, R H Wisniewski, T F
HYDRO-TURBINE AERATION OF RIVERS WITH SUPPLEMENTAL DATA ON CASCADES AERATION
Pulp Paper Mag Canada v 61 Feb 1960 p T45

In addition to discussion of turbine venting efficiencies covered in other references by these authors, the paper briefly discusses the determination of true power loss. Although power output is reduced, water is also saved for later generation, thus partially offsetting the cost of power loss. Also discusses aeration by cascades

EQUIPMENT
streams
turbine injection
cascades

S-6 Scott, R H Wisniewski, T F Lueck, B F Wiley, A J
AERATION OF STREAM FLOW AT POWER TURBINES
Sewage and Ind Wastes v 30 n 12 Dec 1958 p 1496-1505

Describes results of turbine venting at Pixley Dam on Flambeau River, Wis. in June and July of 1957. Indicated gross gain of 525 to 9,471 lb/day-1,000 cfs. Maximum absorption efficiency of 37.3 percent. Maximum DO gain was 4.87 lb/kwhr of power loss. Injection was in annular space between runner ring and conically shaped part of draft chest which surrounds the runner ring. Turbines were double-runner horizontal type

EQUIPMENT
streams
turbine injection

S-7 Shapiro, J
THE CAUSE OF A METALIMNETIC MINIMUM OF DISSOLVED OXYGEN
Limnol and Oceanog v 5 n 2 1960 p 216-227

BASIC STUDIES
reservoirs
experimental
oxidation

S-8 Shastry, J S Fan, L T Erickson, L E Yao, Kuan M
discussion of REAERATION PREDICTION IN NATURAL STREAMS
by Edward L. Thackston and Peter A. Krenkel
Proc ASCE v 95 n SA 6 Feb 1969 p 1186-1202

BASIC STUDIES
streams
reaeration

S-9 Shaver, J W Canter, L W Rowe, D R
PERFORMANCE STUDY OF MUNCIPAL EXTENDED AERATION PLANT
Pub Works v 99 n 3 Mar 1968 p 85-87 148

Study involved comprehensive examination of performance of extended aeration modification of activated sludge process in plant treating domestic waste water from Harahan, La.; plant performance was evaluated by examining coliform reduction, aeration tank oxygenation resulting from two air-flow rates, and overall BOD and suspended solids removal efficiencies (EI 1968)

EQUIPMENT
waste treatment

S-10 Sibiryakov, M A
SANITARNAYA KHARSKTERISTIKA, ETC
(Sanitary Characteristics of Reservoirs)
Kizucheniyu kislorodnogo rezhima vodoemov Sb (Towards the analysis of the oxygen regime of reservoirs Coll)
Trudy AMN SSSR v 10 1951 p 14-43 In Russian

BASIC STUDIES
reservoirs

S-11 Sideman, S Hortacsu, O Fulton, J W
MASS TRANSFER IN GAS-LIQUID CONTACTING SYSTEMS
Ind and Eng Chem v 48 n 7 Jul 1966 p 32-47

Available studies on mass transfer in gas-liquid contacting systems have been critically reviewed; primary weakness in these studies is fact that their correlations are limited to their particular pieces of equipment and ranges of operating conditions; therefore, attempt has been made to organize information into general framework in order to give better insight and understanding to subject; ranges of applicability of these studies have been pointed out, and general correlations have been suggested. 54 refs (EI 1967)

GENERAL
reviews

S-12 Simonsen, R N
AIR FLOTATION DEOILS SOHIO EFFLUENT
Oil and Gas J v 60 n 21 May 21 1962 p 146-148 152-154

Air flotation in combination with chemical flocculation cuts oil in effluent to less than 10 ppm; at one location packaged unit of total pressurization type guards plant effluent discharging to city sewer; at another refinery two-stage API separator was redesigned to provide air flotation unit of recycle type with 3,000 gpm capacity; third installation was made to prevent visible oil films on receiving stream passing through residential and rural areas (EI 1962)

EQUIPMENT
misc uses

S-13 Simonsen, R N
REMOVE OIL BY AIR FLOTATION
Hydrocarbon Processing and Petroleum Refineries v 41 n 5 May 1962 p 145-148

Three refineries have dissolved air flotation units of different types in operation; air flotation was selected over more conventional flocculation and sedimentation process for secondary oil removal because of anticipated smaller equipment sizes and costs, ability to handle varying feed without upsets, and easier sludge disposal; principles of air flotation; conversion of API-type converter to air flotation process; summary of performance (EI 1962)

EQUIPMENT
misc uses

S-14 Sinkoff, M D Geilker, C D Rennerfelt, J G
AN ANALOG COMPUTER FOR THE OXYGEN SAG CURVE
Proc ASCE v 84 n SA6 Nov 1958
Presents a theory for application of the analog computer to stream pollution problems

BASIC STUDIES
streams
theoretical

S-15 Smirnov, D N Kuz'min, A A Saiti, R N
AUTOMATIC CONTROL OF THE AMOUNT OF DISSOLVED OXYGEN IN WASTE WATERS
Vodosnabzh Sanit Tekh v 5 1960 p 18-24
The apparatus employs the polarographic method and its probe consists of two solid electrodes, Au and Zn, protected by the gas-permeable membranes. The electroctrolyte between electrodes is 0.1N NaOAc solution with agar agar. Diffusion of oxygen through the membrane causes depolarization of the indicating electrolyte and flow of current in the circuit of the cell. The apparatus can be used in the laboratory as well as under industrial conditions In Russian

DO ANALYSIS
instrumentation

S-16 Smith, A
SURFACE AERATORS SPIN TO COMEBACK
Water and Wastes Eng v 3 n 12 Dec 1966 p 54-56
Economical method for mixing and furnishing oxygen to wastes in tanks and lagoons; selection of aeration units should not be based on oxygen transfer alone; mixing and tank geometry must also be considered; example of activated sludge plant designed to operate at 15^{o} C with 2 mg of dissolved oxygen per liter of mixed liquor; oxygen requirements are 100 lb/hr (EI 1967)

EQUIPMENT
waste treatment
mechanical
aerators

S-17 Smith, A R
TESTING AND RATING SURFACE AERATORS
Water and Sewage Works 1964 P R264-268

EQUIPMENT
mechanical
aerators

S-18 Smith, H L
BABINE LAKE BUBBLER SYSTEM
Eng J v 51 n 3 Mar 1968 p 39-45
Adaption of air bubbling system for melting lake ice in winter is described; system was installed toward north end of lake in British Columbia; air required is supplied by unperforated galvanized steel pipe to drop-off point of western bench; distance is some 1,595 ft from west shore, at which point depth is 161 ft; connection between two 50-ft lengths of polyethylene pipe is made with galvanized steel insert coupling to which pipe ends are clamped with two stainless steel straps; lake area is subjected to winter conditions with lowest ambient temperature of -47^{o} F, and average winter snowfall amounted to 87 in. EIC-68-CIV 3 (EI 1968)

EQUIPMENT
reservoirs
diffusers
misc uses

S-19 Smutek, Rados Rudis, Miroslav
DIFFUSION OF OXYGEN THROUGH THE FREE SURFACE OF A TURBULENT OPEN CHANNEL FLOW
(Ceskcslov. Akad. Ved, Prague, Czech.) Acta Tech (Prague) v 14 n 3 1969 p 326-351
The transfer rate, K, of oxygen from an oxygen-nitrogen mixture into water flowing under turbulent conditions was studied to determine the mechanism of transfer of oxygen from air into water. To prevent desorption, Na_2SO_3 was used to bond the oxygen in the water through formation of Na_2SO_4. At 18^{o} and surface-active agent (SAA) concentrations of 0.1 mg/l, the

BASIC STUDIES
streams
experimental
reaeration

mass-transfer coefficient for oxygen, K_L, was $Au^{0.683}$, where u is the flow velocity and A is a coefficient depending on the surface roughness of the channel. For a smooth surface, A = 0.00396 and increases with increasing roughness. At low SAA level, K_L is related to u and to the SAA concentrations by $K_L \approx 0.00214\ u^{0.76} C_{SAA}{-0.15}$. There is a limiting concentration, however, beyond which no further effect exists. It was not possible to construct a physical model for the transfer process In Czech

S-20 Sooky, Attila A
LONGITUDINAL DISPERSION IN OPEN CHANNELS
Proc ASCE v 95 n HY 4 Jul 1969 p 1327-1346

BASIC STUDIES
streams
experimental

The effects of cross-sectional geometry and velocity distribution on the dispersion process in straight, uniform open channels with large width-to-depth ratio are investigated. The method of investigation follows Taylor's approach; results apply after the elapse of an initial period during which a constant dispersion coefficient has developed. Under the assumed conditions, the longitudinal dispersion coefficient can be described by a general expression in which the hydraulic radius and the shear velocity are variables. Dispersion varies significantly with cross-sectional shape, width-to-hydraulic radius ratio, and the Reynolds number. The calculated values and pattern of variation are compared to available data for open channels with irregular cross section. 28 refs

S-21 Speece, R E
STREAM OXYGENATION WITH THE U-TUBE
Proc 7th Annual Sanitary and Water Resources Engineering Conf Vanderbilt Univ May 1968

EQUIPMENT
streams
U-tubes

S-22 Speece, R E
THE USE OF PURE OXYGEN IN RIVER AND IMPOUNDMENT AERATION
Paper 24th Purdue Ind Waste Conf May 1969

EQUIPMENT
streams
reservoirs
molecular oxygen

In many situations, using pure oxygen offers an economically competitive alternative for artificial aeration of rivers and impoundments. Proper design of the oxygen injection system can make using pure oxygen very advantageous and achieve efficient absorption. The judicious selection of an oxygen injection system can result in side benefits and flexibility not possible when using air. The application of pure oxygen is economically competitive with air when attempting to aerate water that is about 50 percent saturated with dissolved oxygen or when attempting to achieve near-saturation concentrations in the effluent. Nitrogen concentration can present a serious problem when fish are involved, but can be alleviated by using pure oxygen

S-23 Speece, R E
U-TUBE STREAM RE-AERATION
Public Works N Y v 100 n 8 1969 pp 111-113

EQUIPMENT
streams
U-tubes

The uses of the U-tube system for aerating streams, its operating characteristics, and a modification using dispersed air injection (see also Wat. Pollut. Abstr., 1969, 42, Abstr. No. 894) are discussed, and arrangements for U-tube aeration at a low dam using the cascade to entrain air and at the discharge point of a stratified reservoir to aerate the waters of the hypolimnion are described

S-24 Speece, Richard E Adams, Jack L
U-TUBE OXYGENATION OPERATING CHARACTERISTICS
N. Mex. State U Eng Exp Sta Tech Report No. 45 Las Cruces May 1968
Gives oxygen transfer equation and advantages of U-tube aeration. Results are given for an experimental U-tube system; the system favors depths of 40 ft or more, nominal water velocities greater than 6 fps, and minimum diffuser depths in most cases where air is injected

EQUIPMENT
U-tubes

S-25 Speece, Richard E Adams, Jack L Wooldridge, Carolyn B
U-TUBE AERATION OPERATING CHARACTERISTICS
Proc ASCE v 95 n SA 3 Jun 1969 p 563-574
A modification of U-tube aeration, using low-pressure air injection, was studied on a pilot scale. The pilot U-tube system was made of 4-inch-diameter pipe. Depths of 10, 20, 30, and 40 ft were studied at flow rates up to about 300 gpm. Air injection rates of 5, 10, 15, and 20 percent at different depths were studied. The data were subjected to dimensional analysis and equations were derived for predicting prototype results. The effects of air injection depth, U-tube depth, and nominal water velocity on oxygen transfer economy were evaluated. The results show that water containing zero DO can be 100 percent saturated after one pass through a 40-ft-deep U-tube with 20 percent air injection. In the process of completely saturating water, the U-tube oxygen transfer economy (#O_2/HP-hr) is about the same as conventional aeration systems transferring oxygen to water with zero DO

EQUIPMENT
U-tubes

S-26 Speece, R E Orosco, R
DESIGN OF U-TUBE AERATION SYSTEMS
Proc ASCE v 96 n SA 3 Jun 1970
Four independent parameters were studied in the design of U-tube aeration systems: (1) Air-water ratio; (2) inlet dissolved oxygen concentration; (3) depth; and (4) water velocity. Each different combination of parameters will result in different capital and operating costs. Outlet dissolved oxygen concentration is reported in this study for the following range of independent parameters: (1) Air-water ratio = 5 to 25 percent; (2) inlet dissolved oxygen = 0 to 100 percent saturation; (3) depth = 20 to 40 ft; and (4) water velocity = 3.6 to 9.2 ft per sec. A computer model of the gas transfer equation, adapted to the U-tube aerator was used to evaluate the reaeration coefficient, K_2. Transfer of gases other than oxygen is analyzed.

EQUIPMENT
U-tubes

S-27 Stalmann, V
DIE BSK-TURBINE–EIN NEUES HOCHLEISTUNGS–BELUEFTUNGSSYSGEM DER ABWASSERTECHNIK
Gas- u Wasserfach v 106 n 22 Jun 4 1965 p 613-617
BSK turbine, new and highly efficient aeration system for sewage treatment; performance of economic and improved oxygen entrainment of new, Swiss-designed, aerator are presented in form of tabulated data and graphs on sewage and clean water tests; applicability for smaller plants is pointed out; special features are simplicity of installation obviating complicated blower system, no clogging assuring plant safety, extensive foam destruction and easy adaptability to changing and sudden rise in contamination and density level of sewage to be treated In German (EI 1966)

EQUIPMENT
waste treatment
mechanical
aerators

S-28 Stefan, M J et al
UBER DIE DIFFUSION DER KOHLENSAURE DURCH WASSER UND ALKOHOL
Class II Vienna 1878 p 371 In German

BASIC STUDIES
reaeration

S-29 Stefan, M J et al
UBER DIE DIFFUSION DER FLUSSIGKEITEN
v 79 1879 p 161
This and preceding reference show development of solution to Fick's second law of diffusion In German

BASIC STUDIES
reaeration

S-30 Steller, K
ZASYSANIE POWIETRZA PRZEZ TURBINE WODNA
Polska Adademia Nauk—Prace Instytutu Maszyn Przeplywowych n 33 1966 p 49-63
Air suction by water turbine; results of experiments with model turbines inducting air by leakage and from free surface vortices confirm adverse effect of air contained in water on turbine characteristics; presence of air causes not only drop of efficiency and flow disturbances in rotor and in suction pipe, but also deformation of power characteristics of tested model; vortex and water hammer phenomena observed prove that presence of air influences rise and development of cavitation; observations may be useful for quantitative evaluation of hydraulic losses due to definite amount of air inducted into water flowing through turbine In Polish (EI 1967)

EQUIPMENT
turbine injection

S-31 Storch, B
THE DESIGN, CONSTRUCTION, AND OPERATION OF EXTENDED AERATION PLANTS
Water Pollution Control London v 68 1969 p 40-50
The author discusses the design, construction, and operation of extended aeration plants with diffused-air aeration, and stresses the importance of ease of maintenance and control to ensure that the plant will be operated correctly (WPA 1383 Jul 1969)

EQUIPMENT
waste treatment
diffusers

S-32 Stratton, F E
NITRIFICATION EFFECTS ON OXYGEN RESOURCES IN STREAMS
Dissertation Abstracts v B27 1967 p 3551
Chem Abstracts v 67 1967 p 7997

BASIC STUDIES
streams
oxidation

S-33 Stratton, F E McCarty, P L
PREDICTION OF NITRIFICATION EFFECTS ON DISSOLVED OXYGEN BALANCE OF STREAMS
Environmental Sci and Tech v 1 n 5 May 1967 p 405-410
Method for prediction of dissolved oxygen demand due to biochemical oxidation of inorganic reduced nitrogen compounds utilizes digital computer to estimate nitrifying rate parameters for two-step nitrification process, including kinetic rate constants and initial concentration of nitrifying bacteria; variation of rate constants with temperature is discussed and method for evaluating decay of viable nitriteoxidizing bacteria in absence of its specific substrate is presented; examples comparing predicted and measured nitrogen changes are shown (EI 1967)

BASIC STUDIES
streams
oxidation

S-34 Streeter, H W
MEASURES OF NATURAL OXIDATION IN POLLUTED STREAMS II THE REAERATION FACTOR AND OXYGEN BALANCE
Sewage Works J v 7 n 3 May 1935 p 534

BASIC STUDIES
streams
experimental
reaeration

S-35 Streeter, H W Wright, C T Kehr, R W
MEASURES OF NATURAL OXIDATION IN POLLUTED STREAMS, III, AN EXPERIMENTAL STUDY OF ATMOSPHERIC REAERATION UNDER STREAM FLOW CONDITIONS
Sewage Works J March 1936 p 282

BASIC STUDIES
streams
experimental
reaeration

S-36 Streeter, H W
THE OXYGEN SAG AND DISSOLVED OXYGEN RELATIONSHIPS IN STREAMS
Oxygen Relationships in Streams Tech Report No. W-58-2 Taft Sanitary Eng Center 1958

BASIC STUDIES
streams
reaeration
oxidation

S-37 Streeter, H W Phelps, E B
A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER III FACTORS CONCERNED IN THE PHENOMENA OF OXIDATION AND REAERATION
Public Health Bull No. 146 U S Public Health Service Washington D C 1925 Reprinted 1958

BASIC STUDIES
streams
reaeration
oxidation

S-38 Streif, Abraham
COMPRESSED AIR VERSUS DROUGHT
Compressed Air Magazine v 60 1955 p 232
Proposes using compressed air for artificial turnover to reduce summer evaporation losses by bringing cold bottom water to the surface

EQUIPMENT
reservoirs
diffusers
misc uses

S-39 Sullivan, S L Jr Hardy, B W Holland, C D
FORMATION OF AIR BUBBLES AT ORIFICES SUBMERGED BENEATH LIQUIDS
A I Ch E J v 10 n 6 Nov 1964 p 848-854
Air bubbles were formed at orifices submerged beneath each of 14 liquids, at various angles of inclination; effect of liquid velocity past horizontal, submerged orifice on formation of air bubbles was determined; bubble formation was correlated with physical variables of system by use of Newton's second law of motion; several chemical processes depend upon contacting liquid as continuous phase with gas as dispersed phase (EI 1966)

BASIC STUDIES
bubbles
experimental

S-40 Susag, R H Polta, R C Schroepfer, G J
MECHANICAL SURFACE AERATION OF RECEIVING WATERS
J Water Pollution Control Federation Jan 1966

EQUIPMENT
streams
mechanical aerators

S-41 Susag, Russell H Robins, Maurice L Schroepfer, George J
IMPROVING RIVER AERATION AT AN UNDERFLOW DAM
Proc ASCE v 93 n SA 6 Dec 1967 p 133-144
The aeration occurring in flow through dams can be a significant contribution to the dissolved oxygen resources of a river receiving the oxygen consuming

EQUIPMENT
streams
cascades

organic material of waste waters. Changes in physical or operational characteristics of a dam can affect the rate of aeration. The aeration rate at Lock and Dam No. 2 on the Mississippi River near Hastings, Minn., had been reduced by a factor of three by an increase in tailwater elevation resulting from the construction of another dam downstream. Conversion of the underflow gate structure to an overflow condition by the installation of bulkheads and increasing downstream turbulence almost restored the lost aeration capacity. This study demonstrates that aeration at dams can be improved through changes in operation and indicates that the contribution of dams to river-dissolved oxygen resources should be included in the consideration of dam design and operation

S-42 Symons, J M
WATER QUALITY BEHAVIOR IN RESERVOIRS
Public Health Service Bureau of Water Hygiene Cincinnati Ohio 1969

BASIC STUDIES
reservoirs

S-43 Symons, J M Irwin, W H Robinson, E L Robeck, G G
IMPOUNDMENT DESTRATIFICATION FOR RAW WATER QUALITY CONTROL USING EITHER MECHANICAL- OR DIFFUSED-AIR PUMPING
J American Water Works Assoc Oct 1967

Two methods of artifically destratifying lakes and reservoirs are compared; comparisons are based on water quality improvement and hydraulic performance; results of experiments showed that mechanical- and diffused-air pumping broke up thermal stratification patterns in study lake successfully and improved water quality; dissolved oxygen was added to water and sulfides, reduced iron and manganese were oxidized; although some nitrogen and phosphorous was transported to surface layers during mixing, excessive algal growths did not develop in either case. 19 refs

EQUIPMENT
reservoirs
diffusers

S-44 Symons, J M Robeck, G G
IMPOUNDMENT RESEARCH—1, 2
Water and Wastes Eng (formerly Water Works and Wastes Eng) v 3 n 1, 2 Jan 1966 p 42-44; Feb 1966 p 66-68

Results of study conducted on streamflow regulation projects using method of water quality control in which good-quality stored water is added to stream at times of deteriorating stream water quality; experimental equipment used in studies is reported; studies include artificial destratification and biological transformation of nitrogen. 22 refs (EI 1966)

BASIC STUDIES
reservoirs

S-45 Symons, J M Weibel, S R Robeck, G G
INFLUENCE OF IMPOUNDMENTS ON WATER QUALITY
U S Public Health Service—Environmental Health Ser Water Supply and Pollution Control—Publ 999-WP-18 Oct 1964

Since streamflow regulation is considered as method of water quality control in impoundments, changes in water quality that occur during storage in given environment must be understood and predicted; to aid such study and further research needs, selected references in sanitary engineering and limnology are reviewed with additional section on impoundment releases on downstream water quality as well as operations research for water quality management. 147 refs (EI 1966)

BASIC STUDIES
reservoirs

S-46 Symons, James M Irwin, William H Clark, Robert M Robeck, Gordon G
MANAGEMENT AND MEASUREMENT OF DO IN IMPOUNDMENTS
Proc ASCE v 93 n SA 6 proc paper 5688 Dec 1967 p 181-209

A basis for the comparison of various mechanical devices used for artifically destratifying impoundments by calculating their hydraulic performance based on impoundment stability is recommended. Three problems with this calculation are discussed to avoid misinterpretation, influence of size and geometry on stability, natural changes in stability with time, and the basic hydraulic inefficiency of spring mixing if cold water is raised. Also, a mathematical model is developed for studying the DO budget in impoundments. A solution to the model is presented, using specially designed DO probe equipment. Finally, data are presented on the destratification of a 2,930-acre-ft impoundment in northern Kentucky by pumping. The hydraulic performance of the pump is calculated and the influence of the mixing on the reduced substances and the DO resources in the impoundment is shown. The most favorable time for destratification is also discussed. A bibliography on artificial destratification is included

BASIC STUDIES
reservoirs
EQUIPMENT
reservoirs
diffusers
pumps

S-47 Symons, J M Irwin, W A Robeck, G G
VERBESSERUNG DER WASSERQUALITAET VON TALSPERREN DURCH KUENSTLICHE UMSCHICHTUNG
Vom Wasser v 34 1967 p 158-174

Improvement of reservoir water quality by artificial destratification; commercial-scale experiments on two impoundments, one under study and other undisturbed for comparison purposes, showed high improvement of water quality, due to water destratification by means of pumping and aeration; curves of temperature, oxygen concentration, sulfide and Mn ions concentrations, and phytoplankton, concentration vs time (24 wk) were plotted for depth from 1.5 to 15 m; oxygenation capacity factor and destratification efficiency were used to compute capacity of aeration installation. 15 refs. In German (EI 1968)

BASIC STUDIES
reservoirs

S-48 Symons, James M Irwin, William H Robeck, Gordon G
IMPOUNDMENT WATER QUALITY CHANGES CAUSED BY MIXING
Federal Water Pollution Control Admin Cincinnati Apr 1966

Mechanical pumping was used to artifically destratify a 2,380-acre-ft lake in northern Kentucky. The pump drew water from the bottom and discharged it at the surface. Analysis of samples taken weekly, from May 14 to October 29, 1965, throughout the depth of the lake, showed the influence of mixing on water quality. A nearby lake of nearly equal volume, sampled similarly, was the control. Results showed a warming and oxygenating of the lower layers of the test lake that resulted in the precipitation of manganese and the oxidation of sulfide. Mixing neither increased the concentration of any nitrogen form, or the total hydrolyzable phosphorous, nor decreased the clarity in the surface. There was no increase in algal densities. Some data on work requirements and efficiencies are also given

BASIC STUDIES
reservoirs

S-49 Symons, J M Carswell, J K Robeck, G G
MIXING OF WATER SUPPLY RESERVOIRS FOR QUALITY CONTROL
J American Water Works Assoc v 62 n 5 May 1970 p 322-334

Describes test destratification of relatively small reservoirs (up to 2,900 acre-ft) using either mechanical or diffused air pumping. Dissolved oxygen in

EQUIPMENT
reservoirs
diffusers

the hypolimnion was increased and associated water quality problems were alleviated. Results from one of the test lakes showed reoxygenation efficiencies of 0.7 lb/kwhr for mechanical pumping and 1.7 lb/kwhr for diffused air pumping. Guidelines are given for design and equipment performance evaluation. Includes a summary of water purveyor experience in destratification at 17 reservoirs.

T

T-1 Takahashi, T Fan, L T
SEVERAL DIFFERENT GAS-LIQUID CONTACTORS UTILIZING CENTRIFUGAL FORCE
Kans State U Inst for Systems Design and Optimization Report No. 10 Dec 19 1968 Manhattan Kans

Describes the features of several centrifugal contactors; these contactors are coming into use but as yet there is no literature on design features and fundamental studies. Centrifugal contactors are expected to be widely used because of favorable mass-transfer characteristics

EQUIPMENT
misc equipment

T-2 Tarassov, Victor J Perlis, Harlan J Davidson, Burton
OPTIMIZATION OF A CLASS OF RIVER AERATION PROBLEMS BY THE USE OF MULTIVARIABLE DISTRIBUTED PARAMETER CONTROL THEORY
Water Resources Res v 5 n 3 Jun 1969 p 563-573

Mathematical programming methods applied to water pollution problems have been highly successful, especially in cases where hypothetical models were used. In many applications, linear programming, dynamic programming, or Pontryagin's Maximum Principle methods have been demonstrated, using steady-state Streeter-Phelps system equations at some stage in the optimization study. The application of the Sirazetdinov-Tarassov-Perlis theory of optimal control to the artificial instream aeration problem in polluted rivers is examined. The main concern of the study is to show how artificial instream aeration can be controlled, minimizing the relative cost of operation for several competing design criteria. The economic aspects of cost minimization of this process have important theoretical implications and potential applications to specific water pollution problems. 19 refs

BASIC STUDIES
streams
theoretical
reaeration

T-3 Technical Practice Committee Subcommittee on Aeration in Wastewater Treatment
AERATION IN WASTEWATER TREATMENT—MOP 5
J Water Pollution Control Federation v 41 n 11 Nov 1969 p 1863 v 41 n 12 Dec 1969 p 2026

"Aeration in Wastewater Treatment" is the revised edition of the original Manual of Practice No. 5, "Air Diffusion in Sewage Works," published in 1952. The manual is intended to provide designers, operators, and maintenance personnel of wastewater treatment facilities with the fundamental theory and operational aspects of aeration. First and second installments

EQUIPMENT
waste treatment

T-4 Technical Practice Committee Subcommittee on Aeration in Wastewater Treatment
AERATION IN WASTEWATER TREATMENT—MOP 5
J Water Pollution Control Federation v 42 n 1 Jan 1970 p 51

Third of three installments. Discussion of operation and maintenance of aeration systems, with emphasis on diffusers. Includes short discussion of air blowers

EQUIPMENT
waste treatment

T-5 Teerink, John R Martin, Cecil V
ARTIFICIAL DESTRATIFICATION IN RESERVOIRS OF THE CALIFORNIA STATE WATER PROJECT
J American Water Works Assoc v 61 n 9 Sep 1969 p 436-440

Destratification and aeration in Calif. reservoirs are accomplished by air injection and multiple-level outlet structures. Mixing returns nutrients to the

EQUIPMENT
reservoirs
diffusers
economics

photosynthetic zone for use by organisms, and oxidizes iron and manganese. The effects may be beneficial or detrimental to intended water uses. Evaporation is usually reduced because surface water temperatures are lowered. Dissolved oxygen is increased. Because artificial destratification can produce both benefits and detriments, a study should be made of priority of uses and the effects of mixing, and cost-benefit analyses should be made, placing a value on the various quality changes related to mixing. 16 refs (Knapp-USGS) W69-09883

T-6 Thackston, E L — GENERAL
APPLICATIONS OF ANALOG COMPUTERS IN SANITARY ENGINEERING
Proc of the 3rd Annual Workshop American Assoc of Professors in Sanitary Eng Jun 1968 (Editor)

T-7 Thackston, E L — BASIC STUDIES reservoirs
discussion of CONTROL OF IMPOUNDMENT WATER QUALITY BY ENGINEERING METHODS by J. M. Symons, W. H. Irwin, G. G. Robeck
ASCE Specialty Conf on Current Res into the Effects of Reservoirs on Water Quality Portland Jan 22-24 1968

T-8 Thackston, E L — BASIC STUDIES reservoirs
discussion of MANAGEMENT AND MEASUREMENT OF D.O. IN IMPOUNDMENTS by J. M. Symons, W. H. Irwin, R. M. Clark and G. G. Robeck
Proc ASCE v 94 n SA 4 Aug 1968 p 748-752

T-9 Thackston, Edward L Hays, James R Krenkel, Peter A — BASIC STUDIES streams
LEAST SQUARES ESTIMATION OF MIXING COEFFICIENTS
Proc ASCE v 93 n SA 3 Jun 1967 proc paper 5288 p 47-58

The principle of least squares estimation of nonlinear parameters as a general tool in mathematical modeling can be shown to be applicable to many common problems in sanitary engineering. A digital computer program for accomplishing this procedure is explained, and the results are illustrated for the example of estimating mixing coefficients and mean travel times for measured time- concentration curves. A critical examination of existing estimation procedures shows them to be inaccurate and unreliable. The results of comparative fit of several methods to several hundred curves are presented. If a digital computer is not available, a simple, quick, trial-and-error procedure—outlined in the paper—can be used to produce results more reliable than those given by presently used methods

T-10 Thackston, E L Krenkel, P A — BASIC STUDIES streams reaeration
discussion of BOD AND OXYGEN RELATIONSHIPS IN STREAMS by William E. Dobbins
Proc ASCE v 91 n SA 1 Feb 1965 proc paper 3949 p 84-88

T-11 Thackston, E L Krenkel, P A — BASIC STUDIES streams reaeration
LONGITUDINAL MIXING AND REAERATION IN NATURAL STREAMS
Tech Report No. 7 in Sanitary and Water Resources Eng Vanderbilt U Nashville Tenn 1966

T-12 Thackston, E L Krenkel, P A
LONGITUDINAL MIXING IN NATURAL STREAMS
Proc ASCE v 93 n SA 5 Oct 1967 p 67-90

Various models used to describe or predict longitudinal mixing coefficients are examined and the conditions under which they are expected to apply are elucidated. Several hundred coefficients, both in laboratory flumes and natural streams, were measured under two-dimensional, uniform-flow conditions. The coefficients measured in natural streams are shown to follow equations derived from flume data. The influence of dead zones in the stream on mixing is examined, and it is shown that measured coefficients are much closer to predicted values when the influence of mixing due to the dead zones is separated by the use of a new mixing model

BASIC STUDIES
streams

T-13 Thackston, Edward L Krenkel, Peter A
REAERATION PREDICTION IN NATURAL STREAMS
Proc ASCE v 95 n SA 1 Feb 1969 p 65-94

Reviews the predictive equations of O'Connor-Dobbins, Krenkel, Dobbins, Kalinske, and Churchill; proposes a new formula and gives field data for correlation

BASIC STUDIES
streams
experimental
reaeration

T-14 Thackston, Edward L Krenkel, Peter A
TURBULENT DIFFUSION AND REAERATION
Proc 14th So. Water Resources and Pollution Control Conf held at U of N C Chapel Hill N C Apr 1965 p 197-206

BASIC STUDIES
streams
reaeration

T-15 Thackston, Edward L Speece, R E
REVIEW OF SUPPLEMENTAL REAERATION OF FLOWING STREAMS
J Water Pollution Control Federation v 38 n 10 Oct 1966 p 1614-1622

Diffused air, turbine aeration, weirs, surface aeration, pressure injection, and U-tubes are among methods of providing supplemental aeration in flowing streams; weirs are quite efficient and inexpensive; turbine aeration also appears to be inexpensive, whereas diffused-air and surface aeration are far more costly for same amount of oxygen transfer; pressure injection seems, from its limited use thus far, to be efficient; very effective U-tube process may be applicable to small streams. 20 refs

GENERAL
reviews
EQUIPMENT
streams
diffusers
turbine injection
cascades
mechanical aerators
pressure injection
U-tubes

T-16 Thackston, Edward L Speece, R E
SUPPLEMENTAL REAERATION OF LAKES AND RESERVOIRS
J American Water Works Assoc v 58 n 10 Oct 1966 p 1317-1324

Supplemental aeration and mixing of water in lakes and reservoirs is complicated by stratification and the tremendous volume of water to be moved. A method of oxygenation must provide for distributing oxygen throughout the impounded water, or the water must be mixed to bring it into contact with oxygen at the surface. Most methods of supplemental aeration of impounded waters rely on mixing alone and do not attempt to add oxygen directly. Mixing brings the oxygen-deficient hypolimnion into contact with the atmosphere where it absorbs oxygen and also breaks up the temperature stratification, enabling natural wind forces to cause further mixing action with resulting distribution of oxygen throughout the entire depth of water. Once stratification is broken, continuous pumping is unnecessary; usually intermittent operation will cause complete mixing throughout the season. The most successful attempts to destroy stratification have used compressed air. One of the more promising recent developments is the aerohydraulic gun,

GENERAL
reviews
EQUIPMENT
reservoirs
diffusers
hydraulic guns

or bubble gun, which shoots air bubbles to the surface from underwater tubes. Rising bubbles shatter as they leave the tube mouth and entrain considerably more water than actually flows through the tube. Other techniques for reaerating impounded water are discussed

T-17 Thayer, Richard P Krutchkoff, Richard G
STOCHASTIC MODEL FOR BOD AND DO IN STREAMS
Proc ASCE v 93 n SA 3 Jun 1967 p 59-72

A stochastic model for pollution and dissolved oxygen in streams is obtained. Given the stream parameters and the initial conditions, the model predicts not only the mean amounts of pollution and dissolved oxygen at any point downstream, but also their variability in time. One can determine the proportion of the time that pollution is above any given concentration or that dissolved oxygen is below any given concentration. The theoretical results are tested by comparing them with controlled laboratory experiments and with data from the Sacramento River. It is observed that the means of both pollution and dissolved oxygen follow the equations already obtained by Dobbins ("BOD and Oxygen Relationships in Streams," J of the Sanitary Eng Div, ASCE v 90 n SA 3 Jun 1964 proc paper 3949 p 53). A new and unexpected observation is that the greatest variability in dissolved oxygen occurs at the sag, where it is most critical

BASIC STUDIES
streams
theoretical
reaeration
oxidation

T-18 Thomman, Robert V
MATHEMATICAL MODEL FOR DISSOLVED OXYGEN
Proc ASCE v 89 n SA 5 Oct 1963 p 1-30
Discussion: Alex N Diachishin SA 3:Jun 64:137:3935; Donald J O'Connor and Dominic Di Toro SA 6:Dec 64:117:4171
Closure: SA 6:Dec 64:122:4171

The basic concepts of systems analysis and its application to DO are presented. The mathematical model is developed by viewing a particular body of water such as an estuary as composed of a number of finite segments each comprising a "system" in the classical mathematical sense. A dissolved oxygen balance equation can then be written for each system. A linear systems analysis technique is then used and the DO response resulting from the input forcing functions are derived

BASIC STUDIES
theoretical

T-19 Thomann, R V
RECENT RESULTS FROM MATHEMATICAL MODEL OF WATER POLLUTION CONTROL IN DELAWARE ESTUARY
Water Resources Res v 1 n 3 Third Quarter 1966 p 349-359

Basic concepts of systems analysis and optimum (least-cost) water pollution control are presented; equations utilized to describe time and space variability of dissolved oxygen are presented in systems analysis context, and their usefulness in this form is discussed; application of mathematical model to control of dissolved oxygen in Delaware Estuary is given; recent computer solutions are illustrated, and sensitivity of least-cost dissolved oxygen improvement solutions to rate of atmospheric reaeration is presented (EI 1966)

BASIC STUDIES
estuaries
theoretical

T-20 Thomann, R V
TIME-SERIES ANALYSIS OF WATER-QUALITY DATA
Proc ASCE v 93 n SA 1 Feb 1967 p 1-23

The basic concepts of Fourier and power spectrum analyses are presented in terms of their application to dissolved oxygen and temperature data of the

BASIC STUDIES
estuaries
experimental

Delaware Estuary. The results of Fourier analyses computations performed on hourly data from water-quality monitoring stations are presented. For temperature, more than 92 percent of the total variance is accounted for by the 365-day periodicity. For dissolved oxygen, more than 90 percent of the total variance is accounted for by the annual periodicity and the next four higher harmonics (semi-annual; tri-annual, etc.). The dissolved oxygen variability remaining after removal of the principal Fourier components was found to be approximately normally distributed with an average standard deviation of 0.85 mg per l. Power spectrum analyses of the 24-hr averaged DO residual seconds indicated a peak in the region of 30 to 60 days and for temperature a peak is dominant at 30 days. The analyses all indicate a predominance of low frequency (periods of from 7 days to 1 year and longer) types of phenomena. The implications of the results from a sampling and control point of view are evaluated

T-21 Thomas, H A Jr
THE "SLOPE" METHOD OF EVALUATING THE CONSTANTS OF THE RIRST-STAGE BIOCHEMICAL OXYGEN DEMAND CURVE
Sewage Works J v 9 n 3 May 1937 p 425

BASIC STUDIES
experimental
oxidation

T-22 Thomas, Ivor E
DISPERSION IN OPEN CHANNEL FLOW
PhD Thesis Northwestern U Evanston Ill 1958

BASIC STUDIES
streams

T-23 Toei, Ryozo Matsuno, Ryuichi Nishitani, Keiichi Hayashi, Hideo Imamoto, Tsunehiko
GAS INTERCHANGE BETWEEN BUBBLE PHASE AND CONTINUOUS PHASE IN GAS-SOLID FLUIDIZED BED AT COALESCENCE
Chem Abstracts v 71 1969 p 134

The process of coalescence of bubbles was investigated from the viewpoint of gas interchange (mass transfer) between the bubble phase and the continuous phase. A two-dimensional fluidized bed was used to determine the gas mass-transfer coefficient

BASIC STUDIES
bubbles
experimental

T-24 Truesdale, G A
NEW SOLUBILITY DATA FOR OXYGEN
J of Applied Chem v 5 1955

BASIC STUDIES
experimental
reaeration

T-25 Truesdale, G A Vandyke, K G
THE EFFECT OF TEMPERATURE ON THE AERATION OF FLOWING WATER
Water and Waste Treatment J v 7 n 9 May-Jun 1958

BASIC STUDIES
streams
experimental
reaeration

T-26 Tsivoglou, E C
MODERN CONCEPTS OF BOD-DO RELATIONSHIPS
Ontario Ind Waste Conf 12th–Proc Jun 1965 p 147-157

Summary of more recent work at Robert A. Taft Sanitary Engineering Center on factors involved in stream self-purification, with particular emphasis on relationship of this work to disposal of industrial effluents; analysis of BOD reaction kinetics, as determined on basis of observed BOD rate curves; it is shown that waste treatment plants designed only on basis of 5-day BOD determination will prove inadequate to meet desired DO objectives in receiving streams (EI 1966)

BASIC STUDIES
streams
experimental
oxidation

T-27 Tsivoglou, E C O'Connell, R L Walter, C M Godsil, P J Logsdon, G S
TRACER MEASUREMENTS OF ATMOSPHERIC REAERATION—I LABORATORY STUDIES
J Water Pollution Control Federation v 37 n 10 Oct 1965 p 1343-1362

Evaluates atmospheric reaeration rates in turbulent systems by laboratory experiments using chemically inert radioactive tracer gases; results show Kr 85 and Rn 222 are suitable tracers for oxygen gas. Tests indicate reaeration in turbulent systems takes place in two separate consecutive steps—diffusion of gas across the liquid-air interface, and subsequent mixing and dispersion of the dissolved gas throughout the main body of water

BASIC STUDIES
streams
experimental
reaeration

T-28 Tisvoglou, E C
TRACER MEASUREMENT OF STREAM REAERATION
Federal Water Pollution Control Admin Div of Tech Services U S Dept Interior Washington D C 1967

Reports laboratory and field trials on tracer measurement of stream reaeration

BASIC STUDIES
streams
experimental
reaeration

T-29 Tsivoglou, E C Cohen, J B Shearer, S D Godsil, P J
TRACER MEASUREMENT OF STREAM REAERATION—II FIELD STUDIES
J Water Pollution Control Federation Washington D C 20016 v 40 n 2 pt 1 Feb 1968 p 285-305

New method for accurate and independent direct measurement of gas transfer and reaeration capacity of natural streams is presented; fluorescent dye, dispersion indicator (tritium), and gaseous tracer (krypton-85) were released in main flow of Jackson River from Covington to Clifton Forge, Va.; results show that tracer method may be used in polluted or unpolluted rivers, regardless of sludge deposits, algae, and dissolved oxygen levels; method provides predictions in general range of values predicted by previous investigators. 10 refs

BASIC STUDIES
streams
experimental
reaeration

T-30 Tsivoglou, E C Wallace, J R
HYDRAULIC PROPERTIES RELATED TO STREAM REAERATION
Georgia Inst of Tech Unnumbered Undated

BASIC STUDIES
streams
experimental
reaeration

T-31 Tullis, J P Skinner, M M
REDUCING CAVITATION IN VALVES
Proc ASCE v 94 n HY 6 Nov 1968 p 1475-1488

The variation of cavitation inception, with and without air injection and as a function of valve opening, are reported for a 12-in. ball valve in a 12-in. butterfly valve with water as the test fluid. Air is injected through the valve stem and side ports of the butterfly valve and through side ports in the ball valve. The water supply is approximately 38° F with an air content of about 70 percent of saturation. Air injection into the separation zone below the valves is shown to effectively eliminate or significantly reduce cavitation. (J. F. Lafferty Applied Mechanics Rev v 22 n 11 Nov 1969 rev 8870.)

CAVITATION

T-32 Tullis, J P Marschner, B W
REVIEW OF CAVITATION RESEARCH ON VALVES
Proc ASCE v 94 n HY 1 Jan 1968 p 1-16

Critical cavitation indices are presented for 12-in. ball and 12-in. butterfly valve installed in closed conduit system with sudden expansion downstream

CAVITATION

of valves; tests were conducted under normal operating conditions to find effect of injecting air and water at various locations on critical cavitation index; it was found that injecting water into sudden expansion below valves does not affect cavitation; injecting small quantities of air into separation zones below valves materially reduces cavitation intensity and critical cavitation index. 12 refs (EI 1968)

T-33 Tyler, R
POLLUTED STREAMS CLEARED UP BY AERATION
Civil Eng v 16 1946 p 348-349

EQUIPMENT
streams
diffusers

T-34 Tyler, Richard G
ACCELERATED REAERATION
Sewage Works J v 14 n 4 Jul 1942 p 834-838

This paper contains one of the early proposals for the use of diffusers for supplemental reaeration of streams

EQUIPMENT
streams
diffusers

T-35 Tyler, Richard G
STREAM POLLUTION, ACCELERATED REAERATION
Civil Eng (London) v 38 Jan 1943 p 7-9

EQUIPMENT
streams

U

No references

V

V-1 Vanderhoof, R A — BASIC STUDIES; streams; reservoirs

CHANGES IN WASTE ASSIMILATION CAPACITY RESULTING FROM STREAMFLOW REGULATION

U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965

Discusses dissolved oxygen changes in a reservoir and the control of waste assimilative capacity downstream by flow augmentation and peaking power discharges

V-2 Van der Kroon, G T M — BASIC STUDIES; experimental; reaeration

EFFECT OF SUSPENDED COMPOUNDS ON THE RATE OF OXYGEN TRANSFER INTO WATER SOLUTIONS

Vodni Hospodarstvi (Czech) v 6 1968 p 255

THE INFLUENCE OF SUSPENDED SOLIDS ON THE RATE OF OXYGEN TRANSFER INTO AQUEOUS SOLUTIONS

Water Res v 2 1968 p 26

V-3 Van Wijngaarden, L — CAVITATION

ON GROWTH OF SMALL CAVITATION BUBBLES BY CONVECTIVE DIFFUSION

Int J Heat and Mass Transfer v 10 n 2 Feb 1967 p 127-134

In calculation of bubble growth due to convective diffusion of gas (mainly air) by B. R. Parkin and R. W. Kermeen, vapor content of bubbles and surface tension were not taken into account; allowance is made for these effects; V. G. Levich's model is advanced for determination of mass flux in bubbles; growth results are compared with Parkin and Kermeen experimental data. 9 refs (EI 1967)

V-4 Varma, M M DiGiano, F — BASIC STUDIES; experimental; oxidation

KINETICS OF OXYGEN UPTAKE BY DEAD ALGAE

J Water Pollution Control Federation v 40 n 4 Apr 1968 p 613

V-5 Velz, C J — BASIC STUDIES; streams; reareation; oxidation

DEOXYGENATION AND REOXYGENATION

Trans ASCE v 104 1939 p 560

Presents a nomograph for calculating atmospheric reaeration in turbulent systems

V-6 Velz, C J — BASIC STUDIES; streams; reaeration

FACTORS INFLUENCING SELF-PURIFICATION AND THEIR RELATION TO POLLUTION ABATEMENT

Sewage Works Journal v 19 n 4 1947

V-7 Velz, C J — BASIC STUDIES; streams; oxidation

SIGNIFICANCE OF ORGANIC SLUDGE DEPOSITS

Oxygen Relationships in Streams Tech Report W58-2 Robert A. Taft Sanitary Eng Center U S Public Health Service 1958

V-8 Verduin, Jacob — BASIC STUDIES; reservoirs; photosynthesis

discussion of PHOTOSYNTHESIS AS A FACTOR IN THE OXYGEN BALANCE OF RESERVOIRS by C.H.J. Hull

U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No. 999-WP-30 Jun 1965 p 91-94

Discusses establishing the ecological relationships in photosynthetic oxygenation rather than applications to sanitary engineering; gives a table showing amount of oxygen derived from natural phytoplankton communities

V-9 Vinberg, G G
ZHACHENIE FOTOSINTEZA JLYA OBOGASHCHENIYA VODY KISLORODOM PRI SAMOOCHISHCHENII ZAGRYAZNENNYKH VOD
(Significance of Photosynthesis for Oxygen Enrichment of Water During Self-purification of Polluted Waters)
Trudy Vsesoyuz Gidrobiol Obshchestva v 6 1955 p 46-69 In Russian

BASIC STUDIES
photosynthesis

W

W-1 Wagner, H
VOITH-FORSCHUNG UND KONSTRUKTION (Voith—Research and Construction)
v 1 1955 p 1311 In German

EQUIPMENT
streams

W-2 Wagner, H
THE ARTIFICIAL AERATION OF HARNESSED STREAMS
Special Communications to the German Hydrological Year Book No. 15 Published by the Federal Office for Hydrology Coblenz (1956) In German

EQUIPMENT
streams
turbine injection

W-3 Wagner, H
THE ARTIFICIAL AERATION OF CANALIZED RIVERS
Bes Mitt Dtsch Gewasserkundlichen J No. 15 1956
Water Pollution Abstracts (Brit) v 30 1957 p 2222 In German

EQUIPMENT
streams

W-4 Wagner, H
EXPERIMENTS WITH ARTIFICIAL AERATION OF RIVER WATER
Deutsche Gewasserkundliche Mitteilungen v 2 n 4 1958 p 73-79
Results of aeration experiments at the Poppenweiler Powerplant on the Neckar, 1957 In German

EQUIPMENT
streams
turbine injection

W-5 Walker, J D
CROSS-ROLL AERATION ELIMINATES SHORT CIRCUITING
Water and Wastes Eng (formerly Water Works and Wastes Eng) v 3 n 1 Jan 1966 p 57-59
Effects of cross-roll aeration method in long-period reaeration processes to eliminate short circuiting so that progressive synthesis will take place and finished sludge will be endogenous before reentry into contact are outlined; how diffusers and air headers are arranged for cross-roll aeration; tests in parallel tanks (EI 1966)

EQUIPMENT
waste treatment
diffusers

W-6 Wallace, J R Reheis, H F
HYDRAULIC PROPERTIES OF THE SOUTH AND FLINT RIVERS IN THE VICINITY OF ATLANTA, GEORGIA
Georgia Inst Technol Atlanta prepared for the FWPCA Washington D C Feb 1969
Provides physical data for an investigation on stream reaeration capacity. Physical characteristics of the streams are discharge, flow depth, stream width, flow velocity, hydraulic radius, wetted perimeter, and stream slope. Predictions of reaeration capacity are made from available predictive models

BASIC STUDIES
streams
experimental
reaeration

W-7 Welch, P S
LIMNOLOGY, 2D ED
McGraw-Hill New York N Y 1952 528 p

GENERAL

W-8 Weston, R F
STUDIES IN ENTRAINMENT AERATION
J Water Pollution Control Federation v 34 n 4 Apr 1962 p 342-353
Report of work undertaken to better define fundamentals of operation and to determine effects of diameter, blade sizes, number of blades, speed of rotation, submergence, and other variables on horsepower requirements and oxygen transfer (EI 1962)

EQUIPMENT
mechanical
aerators

W-9 Wezenak, Chester T Gannon, John J
EVALUATION OF NITRIFICATION IN STREAMS
Proc ASCE v 94 n SA 5 Oct 1968 p 883-895
A simplified procedure for evaluating nitrification progression in a stream is given. Data are presented for the Clinton River between Pontiac and Rochester, Mich. which show rapid inorganic nitrogen oxidation in this section of the river. Graphical and analytical techniques for evaluating nitrification parameters and progression are described

BASIC STUDIES
streams
experimental
oxidation

W-10 Whipple, W
ECONOMICS OF INDUCED RIVER AERATION
Chemical Engineering Progress v 65 n 97 1969 (book review)

EQUIPMENT
streams
economics

W-11 Whipple, W Jr Coughlan, F P Jr
INSTREAM AERATORS FOR POLLUTED RIVERS
Reprint 1086 ASCE National Water Resources Meeting Memphis Tenn Jan 26-30 1970
Describes field tests of instream use of mechanical aerator and diffuser. Comparison on basis of transfer efficiency and cost shows mechanical aerator to be superior. Efficiency of mechanical aerator was about 2 to 3 lbs oxygen/hp-hr; diffuser had efficiency about two-thirds that amount. Gives good example of cost analysis

EQUIPMENT
streams
mechanical aerators
diffusers
economics

W-12 Whipple, W Jr Hunter, J V Davison, B Dittman, F W Yu, Shaw L
IN-STREAM AERATION OF POLLUTED RIVERS
Rutgers—The State U New Brunswick N J Water Resources Res Inst
Mechanical and diffuser instream aerators were tested on the Upper Passaic River and proved a practical and economical method of adding dissolved oxygen to polluted streams. The tests were conducted in conjunction with research into photosynthesis, benthal oxygen demand, and mass balance of BOD in that river system. Systems of aerators were designed to provide for meeting water quality objectives of dissolved oxygen and cost estimates made. Alternative costs of meeting the same objectives by means of advanced effluent treatment alone appear to be several times as great. It is concluded that instream aeration may provide a feasible alternative to advanced waste treatment for polluted rivers, as a supplement to secondary waste treatment W69-09555

EQUIPMENT
streams
mechanical aerators
diffusers

W-13 White, M T
SURFACE AERATION AS SECONDARY TREATMENT SYSTEM
Tappi v 48 n 10 Oct 1965 p 128A-132A
Fourteen 60-hp surface aerators were installed as secondary treatment system in one basin of existing two-basin retention lagoon; BOD is reduced by about 36 percent in passing through first basin; overall reduction for summer averaged 88 percent; oxygen transfer efficiency was 3.1 lb/hp-hr at design load range; installation and operating costs (EI 1966)

EQUIPMENT
waste treatment
mechanical aerators

W-14 Whitman, W G
TWO-FILM THEORY OF GAS ABSORPTION
Chemical and Metallurgical Engineering v 29 1923 p 146

BASIC STUDIES
theoretical
reaeration

W-15 Wiebe, A H
THE EFFECT OF DENSITY CURRENTS UPON THE VERTICAL DISTRIBUTION OF TEMPERATURE AND DISSOLVED OXYGEN IN NORRIS RESERVOIR
J Tenn Academy Sci v 15 1940 p 301-308
BASIC STUDIES
reservoirs

W-16 Wiley, A J Lueck, B F Scott, R H Wisniewski, T F
COOPERATIVE STATE-INDUSTRY STREAM STUDIES—LOWER FOX RIVER, WISCONSIN
Sewage and Ind Wastes v 29 Jan 1957 p 76
EQUIPMENT
streams
turbine injection

W-17 Wiley, A J Lueck, B F Scott, R H Wisniewski, T F
COMMERCIAL-SCALE OPERATION OF TURBINE AERATION ON WISCONSIN RIVERS
Sewage and Ind Wastes v 32 n 2 Feb 1960 p 186
EQUIPMENT
streams
turbine injection

W-18 Wiley, A J Lueck, B F
TURBINE AERATION AND OTHER METHODS OF REAERATING STREAMS
Tappi v 43 1960 p 241
EQUIPMENT
streams
turbine injection

W-19 Wiley, A J Lueck, B F Scott, R H Wisniewski, T F
COMMERCIAL-SCALE STREAM REAERATION
J Water Pollution Control Federation v 34 n 4 Apr 1962 p 401
EQUIPMENT
streams
turbine injection

Review of present status of commercial-scale stream aeration as means for accelerating recovery of oxygen-depleted waters and of increasing working capacity of rivers subjected to heavy loadings of biochemical and chemical oxygen demand

W-20 Wiley , A J Parkinson, L Gehm, H W Wisniewski, T F Bartsch, H F
RIVER REAERATION
Paper Trade J v 124 Mar 20 1947 p 123
EQUIPMENT
streams
diffusers

A method suggested by Professor Tyler of the University of Wash. consisting of diffusing compressed air beneath the surface of a river which has been polluted for the purpose of maintaining minimum levels of dissolved oxygen, has been tried in full scale on a Wis. river. The experimental setup consisted of an aerating station located at a power dam downstream from a sulphite mill at a point where a serious sag in dissolved oxygen occurred in the stream during low summer flows. Employing carborundum diffusers with a total area of 319 sq ft set at a depth of about 10 ft and fed by a compresser capable of supplying 1,550 cu ft of air per minute at 5 psi it was possible to add to the stream an average of close to 1.5 tons of oxygen per day at a flow of 800 cfs. This together with the immediate satisfaction of a portion of the BOD of the stream water, attributable to aeration, caused a marked movement upstream of the zone of recovery. Hence the process appears to be a useful tool in accelerating the recovery of a polluted stream shortening to a considerable degree the distance of passage required for oxidation of the waste and serves to prevent anerobic conditions and attending nuisance.

Extensive test data collected during operation of the unit are summarized in this paper including biological observations with respect to stream flora and fauna. Recommendations with respect to application, requirements, design, and efficiency are included

W-21 Winberg, G G Sivko, T N
SIGNIFICANCE OF PHOTOSYNTHETIC AERATION IN OXYGEN BALANCE OF POLLUTED WATERS
Int J Air and Water Pollution v 6 May-Aug 1962 p 267-275
Method of calculation of elements of oxygen balance; example calculations of atmospheric aeration oxygen consumption of riverbed and sessile vegetation and photosynthetic reaeration by fixed vegetation (EI 1962)

BASIC STUDIES
streams
photosynthesis
oxidation
reaeration

W-22 Wirts, J J
CLEANING AIR DIFFUSION MEDIA
Water and Sewage Works v 94 1947

EQUIPMENT
diffusers

W-23 Wisniewski, T F
IMPROVEMENT OF THE QUALITY OF RESERVOIR DISCHARGES THROUGH TURBINE OR TAILRACE AERATION
U S Dept Health Education Welfare Symposium on Streamflow Regulation for Quality Control Public Health Service Pub No 999-WP-30 Jun 1965 p 299-316
Review the status of commercial-scale stream aeration on the Flambeau River, Fox River, and Wisconsin River; an evaluation of capital and operating costs is given for hydroturbine aeration

EQUIPMENT
streams
turbine injection
diffusers

W-24 Wolf, P
KORREFERAT ZU: IMHOFF, KUNSTLICHE BELUFTUNG FUR DEN BALDENEYSEE UND DIE UNTERE RUHR
(Coreview of: Imhoff, Artificial Aeration for the Baldeney Lake and the Lower Ruhr)
Gewasserschutz–Wasser–Abwasser Band 1 Aachen 1968

EQUIPMENT
streams
reservoirs
diffusers
turbine injection
mechanical aerators
economics

W-25 Wood, R
COMPARISON STUDIES OF WINKLER VS OXYGEN SENSOR
J Water Pollution Control Federation v 41 n 12 Dec 1969 p 2002
Determination of dissolved oxygen levels in waste water treatment and effluent disposal are of great use in a number of ways. In-plant laboratory studies of using a polarographic oxygen sensor in comparison with the more common Winkler method were conducted. Advantages found were: (a) the preparation and standardization of reagent solution are eliminated: (b) time spent in analysis is reduced; (c) the method is less tedious; and (d) correlation with the Winkler method is excellent. Laboratory experiences and data support these conclusions

DO ANALYSIS
instrumentation

W-26 Wurtz, B
EFFECTS OF HEATED DISCHARGES ON AQUATIC LIFE AND WATER USE
ASME–Paper 61-WA-142 for meeting Nov 26-Dec 1 1961
Effects of heated discharges on biological structure of receiving stream; fish and bottom organisms discussed insofar as they are directly affected by heat; water uses that are temperature limited, also discussed, as are relationships between dissolved oxygen and temperature (EI 1962)

BASIC STUDIES
streams

X

No references

Y

Y-1 Yen, Ben Chie
discussion of OXYGEN TRANSFER FROM FALLING WATER DROPLETS by Charles E. Carver, Jr.
Proc ASCE v 95 n SA 6 Apr 1969 p 1203-1205

BASIC STUDIES
experimental
reaeration

Y-2 Yotsukura, Nobuhiro Fiering, Myron B
NUMERICAL SOLUTION TO A DISPERSION EQUATION
Proc ASCE v 90 n HY 5 Sep 1964 p 83-104

BASIC STUDIES
streams
theoretical

Z

Z-1 Zieminski, S A Caron, M M Blackmore, R B
BEHAVIOR OF AIR BUBBLES IN DILUTE AQUEOUS SOLUTIONS
Ind and Eng Chem—Fundamentals v 6 n 2 May 1967 p 233-242

Total transfer rate may be profoundly affected by some of investigated substances, e.g., heptanoic acid at concentration of 10 ppm increased rate of oxygen transfer by 180 percent; effects discussed in this report depend on air dispersing system; since principal action of substances appears to be in preventing coalescence of bubbles, their effectiveness will improve in systems where possibility of coalescence is greater; applicability to aeration systems, as used in fermentation processes and in treatment of sewage by bio-oxidation. 24 refs (EI 1967)

BASIC STUDIES
waste treatment
bubbles
experimental

Z-2 Zieminski, Stefan A Raymond, Delmar R
USE OF CHEMICAL ADDITIVES TO IMPROVE AERATION RATES: STUDY OF THE BEHAVIOR OF SINGLE BUBBLES—PROGRESS REPORT NO. 3a
Federal Water Pollution Control Admin Report R 848-4 Washington D C 1967

This report consists of two parts. Part 1 deals with methods of measuring rates of volume change of a rising gas bubble, its surface area, velocity of rise, and the instantaneous mass-transfer coefficient. The principle of this method was discussed in Progress Report No. 2a (1966). However, because of the changes introduced and the reproducibility tests conducted, the method is discussed in this report in detail. Special attention is given to the method of bubble release that proved to be an important factor affecting the consistency of results. Part 2 discusses effects of a homologous series of normal alcohols on mass-transfer and drag coeffieients of a carbon dioxide bubble. Carbon dioxide was used in the tests instead of air because of its higher solubility in water permitting greater accuracy of results. It may be expected that similar effects would take place in the case of air bubbles and thus help to better understand and possibly improve aeration systems. The study showed the depressing effect of an alcohol on K_L increases with its chain length and concentration. A similar consistency of effects was also noticed in the case of drag coefficient which increased with concentration and chain length of the alcohol. 55 refs

BASIC STUDIES
bubbles
experimental
reaeration

Z-3 Zieminski, Stefan A Lessard, Richard R
USE OF CHEMICAL ADDITIVES TO IMPROVE AERATION RATES: STUDY OF MODELS OF AIR DISPERSERS—PROGRESS REPORT NO. 3b
Federal Water Pollution Control Admin Report R 848-4 Washington D C 1967

The investigation presented in this report deals with a method for improving the rates of aeration. In order to achieve this objective small quantities of some organic substances are introduced in the zone of bubble formation. These additives decrease bubble coalescence and improve the rate of transfer because of the substantial increase in the interfacial surface area. The tests were conducted with n-octanol, 4-methyl-2-pentanol and heptaoic acid. At a concentration of 1 ppm the n-octanol and 4-methyl-2-pentanol showed an improvement in the rate of aeration of 70 percent over that in pure water. At a concentration of only 0.5 ppm n-octanol gave an improvement in the rate of transfer of 30 percent. Since the design of the aerator and the agent were not optimized, it may be expected that still better effect could be obtained in a large-scale installation. Federal Water Pollution Control Administration Grant WP-00562-04. 36 refs

BASIC STUDIES
bubbles
experimental
reaeration

Z-4 Zieminski, S A Raymond, D R
EXPERIMENTAL STUDY OF BEHAVIOR OF SINGLE BUBBLES
Chem Eng Sci v 23 n 1 Jan 1968 p 17-28

BASIC STUDIES
bubbles
experimental

Method is described for measurements of rates of volume change of rising gas bubble, its surface area, velocity of rise, and instantaneous mass-transfer coefficient; principle of this method is to follow, by means of high-speed photography, motion of bubble simultaneously with changes in volume as indicated by capillary of dilatometer; in this way almost continuous record is obtained of bubble volume, shape, and oscillation, as related to height of bubble in liquid and time elapsed from moment of bubble release; relevant to operation of air lifts, mammoth pumps, and sulfur pumping in Frasch process. 31 refs (EI 1968)

Z-5 Zhavoronkov, N M Romankov, P G
OSNOVNYE NAPRAVLENIYA NAUCHNYKH ISSLEDOVANII V OBLASTI MASSOOBMENNYKH PROTESESSOV KHIMICHESKOI TEKHNOLOGII
Khimicheskaya Promyshlennost n 2 Feb 1965 p 1-4

BASIC STUDIES
reaeration

Main trends in scientific research of mass-exchange processes in chemical technology; present state and future program of research concerned with studies of theoretical problems of physicochemical hydrodynamics and mass exchange; phase equilibria and constants in systems gas-liquid, vapor-liquid, and liquid-liquid, particularly in nonideal and multicomponent systems; calculations of basic processes of mass exchange; mathematical modeling and descriptions of technology of mass-exchange processes. In Russian (EI 1966)

BIBLIOGRAPHY INDEX

7-1750 (1-70)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
*Fahrenheit degrees (change)**	*5/9 exactly*	*Celsius or Kelvin degrees (change)**
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

Bureau of Reclamation responsibility for maintaining or enhancing the water quality associated with its projects has resulted in a comprehensive program of research in water quality and pollution control. A literature search and state-of-the-art review to determine the need for future research in reaeration of streams and reservoirs revealed a large number of references concerning the application of aeration methods and equipment to waste treatment. Generally, the application of this technology to aeration of large volumes of water such as rivers and reservoirs remains to be developed, although several applicable references were found. Questions regarding atmospheric reaeration in streams remain unresolved. Research is also needed regarding the aeration capability of hydraulic structures and control devices, development of new methods and equipment, effects of dissolved air on cavitation, and comparative economics of various methods and equipment. Ecological effects of reaeration are being considered in a separate review.

ABSTRACT

Bureau of Reclamation responsibility for maintaining or enhancing the water quality associated with its projects has resulted in a comprehensive program of research in water quality and pollution control. A literature search and state-of-the-art review to determine the need for future research in reaeration of streams and reservoirs revealed a large number of references concerning the application of aeration methods and equipment to waste treatment. Generally, the application of this technology to aeration of large volumes of water such as rivers and reservoirs remains to be developed, although several applicable references were found. Questions regarding atmospheric reaeration in streams remain unresolved. Research is also needed regarding the aeration capability of hydraulic structures and control devices, development of new methods and equipment, effects of dissolved air on cavitation, and comparative economics of various methods and equipment. Ecological effects of reaeration are being considered in a separate review.

ABSTRACT

Bureau of Reclamation responsibility for maintaining or enhancing the water quality associated with its projects has resulted in a comprehensive program of research in water quality and pollution control. A literature search and state-of-the-art review to determine the need for future research in reaeration of streams and reservoirs revealed a large number of references concerning the application of aeration methods and equipment to waste treatment. Generally, the application of this technology to aeration of large volumes of water such as rivers and reservoirs remains to be developed, although several applicable references were found. Questions regarding atmospheric reaeration in streams remain unresolved. Research is also needed regarding the aeration capability of hydraulic structures and control devices, development of new methods and equipment, effects of dissolved air on cavitation, and comparative economics of various methods and equipment. Ecological effects of reaeration are being considered in a separate review.

ABSTRACT

Bureau of Reclamation responsibility for maintaining or enhancing the water quality associated with its projects has resulted in a comprehensive program of research in water quality and pollution control. A literature search and state-of-the-art review to determine the need for future research in reaeration of streams and reservoirs revealed a large number of references concerning the application of aeration methods and equipment to waste treatment. Generally, the application of this technology to aeration of large volumes of water such as rivers and reservoirs remains to be developed, although several applicable references were found. Questions regarding atmospheric reaeration in streams remain unresolved. Research is also needed regarding the aeration capability of hydraulic structures and control devices, development of new methods and equipment, effects of dissolved air on cavitation, and comparative economics of various methods and equipment. Ecological effects of reaeration are being considered in a separate review.

REC-OCE-70-55
King, D L
REAERATION OF STREAMS AND RESERVOIRS—ANALYSIS AND BIBLIOGRAPHY
Bur Reclam Rep REC-OCE-70-55, Div Gen Res, Dec 1970. Bureau of Reclamation, Denver, 131 p, 2 fig, 7 tab, 448 ref

DESCRIPTORS—/ *aeration/ *streams/ *reservoirs/ instrumentation/ oxygen sag/ mathematical analysis/ theory/ mass transfer/ equipment/ *dissolved oxygen/ methodology/ industrial waste treatment/ sewage treatment/ water quality/ efficiencies/ economics/ *bibliographies/ *reviews/ cavitation/ biochemical oxygen demand/ *reaeration/ oxygen requirements
IDENTIFIERS—/ cavitation control/ oxygen exchange/ empirical equations/ formulas

REC-OCE-70-55
King, D L
REAERATION OF STREAMS AND RESERVOIRS—ANALYSIS AND BIBLIOGRAPHY
Bur Reclam Rep REC-OCE-70-55, Div Gen Res, Dec 1970. Bureau of Reclamation, Denver, 131 p, 2 fig, 7 tab, 448 ref

DESCRIPTORS—/ *aeration/ *streams/ *reservoirs/ instrumentation/ oxygen sag/ mathematical analysis/ theory/ mass transfer/ equipment/ *dissolved oxygen/ methodology/ industrial waste treatment/ sewage treatment/ water quality/ efficiencies/ economics/ *bibliographies/ *reviews/ cavitation/ biochemical oxygen demand/ *reaeration/ oxygen requirements
IDENTIFIERS—/ cavitation control/ oxygen exchange/ empirical equations/ formulas

REC-OCE-70-55
King, D L
REAERATION OF STREAMS AND RESERVOIRS—ANALYSIS AND BIBLIOGRAPHY
Bur Reclam Rep REC-OCE-70-55, Div Gen Res, Dec 1970. Bureau of Reclamation, Denver, 131 p, 2 fig, 7 tab, 448 ref

DESCRIPTORS—/ *aeration/ *streams/ *reservoirs/ instrumentation/ oxygen sag/ mathematical analysis/ theory/ mass transfer/ equipment/ *dissolved oxygen/ methodology/ industrial waste treatment/ sewage treatment/ water quality/ efficiencies/ economics/ *bibliographies/ *reviews/ cavitation/ biochemical oxygen demand/ *reaeration/ oxygen requirements
IDENTIFIERS—/ cavitation control/ oxygen exchange/ empirical equations/ formulas

REC-OCE-70-55
King, D L
REAERATION OF STREAMS AND RESERVOIRS—ANALYSIS AND BIBLIOGRAPHY
Bur Reclam Rep REC-OCE-70-55, Div Gen Res, Dec 1970. Bureau of Reclamation, Denver, 131 p, 2 fig, 7 tab, 448 ref

DESCRIPTORS—/ *aeration/ *streams/ *reservoirs/ instrumentation/ oxygen sag/ mathematical analysis/ theory/ mass transfer/ equipment/ *dissolved oxygen/ methodology/ industrial waste treatment/ sewage treatment/ water quality/ efficiencies/ economics/ *bibliographies/ *reviews/ cavitation/ biochemical oxygen demand/ *reaeration/ oxygen requirements
IDENTIFIERS—/ cavitation control/ oxygen exchange/ empirical equations/ formulas